REINFORCEMENT INTERVAL
AND
INTERRESPONSE TIME REINFORCEMENT
AS
DETERMINANTS OF RESPONSE RATE

by

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ABSTRACT

Reinforcement may affect responding by strengthening a response so as to increase its frequency of occurrence and by differentiating a response with respect to some of its properties. It has been suggested that response rate is controlled by the strengthening effect of reinforcement on responding and by the differential reinforcement of the time between responses, the interresponse time. The strengthening and differentiating effects of reinforcement on response rate are usually confounded in studies of responding on simple reinforcement schedules. This thesis analyzed the effects of reinforcement interval (a strengthening variable) and interresponse time reinforcement (a differentiating variable) on response rate by independently manipulating them over a range of values. Food-deprived pigeons pecking illuminated disks for food reinforcement were exposed to novel reinforcement schedules which allowed simultaneous differential reinforcement of interresponse times and control of reinforcement interval. With these schedules interresponse time reinforcement was the principal determinant of response rate while reinforcement interval played a secondary role. Although both variables made independent contributions to the determination of response rate, they did not interact over the range of values investigated. This thesis documents the existence of separable strengthening and differentiating effects of reinforcement on response rate and emphasizes the importance of interresponse time differentiation in the determination of response rate.

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Chapter 1

Introduction

The frequency with which an animal performs an act is determined by a multiplicity of variables in the environment and within the animal. Changes in physiological states, in the external environment, and in the animal's experience all influence the probability that a particular behavior will occur. As Thorndike documented in 1911, one important determinant of future occurrences of a behavior can be a change in the environment following the occurrence of that behavior.

Thorndike placed cats, dogs, and chicks in boxes which could be escaped by the operation of a latching device. The animals came to perform the latch-releasing act more quickly as training progressed, each performance being followed by release from the box and access to food. Thorndike summarized his observations on the relationship between behavior and what follows it in his "Law of Effect". He described the effect of positive changes in the environment upon behavior as follows (1911, p. 244):

> Of several responses made to the same situation, those which are accompanied or closely followed by satisfaction to the animal will, other things being equal, be more firmly connected with the situation, so that, when it recurs, they will be more likely to recur.

Thorndike's formulation of the Law of Effect dealt with the strengthening of connections between situations and responses made to those situations. His law stated that these connections were strengthened by some favorable change in the environment or a "satisfying state of affairs" (Thorndike, 1911, p. 245). Skinner (1938) studied the effects of satisfying states of affairs, or reinforcement, on responding without reference to situation-response connections. He recognized two distinct effects of reinforcement on a response. The principal effect was to "strengthen" responses, producing an increase in their frequency of occurrence. A secondary effect was that of "differentiating" responding by increasing the frequency of responses with particular values. The strengthening effect is similar to that studied by Thorndike, although Skinner dealt with the strengthening of responding rather than of situation-response connections as did Thorndike. The differentiating effect of reinforcement was a new principle and important as the basis for the production of novel behavior. The effect is illustrated by one of Skinner's experiments with differentiation of the force of lever pressing. He presented food reinforcement to hungry rats only if the force of their press on a lever exceeded some minimum value. By gradually increasing this criterion value he was able to induce the rats to produce responses with forces they had not previously exhibited.

The two effects of reinforcement noted by Skinner depend upon the definition of the response class followed by reinforcement. The definition may be at the level of "a peck on a disk", in which case the strengthening effect of reinforcement should produce an increase in the rate of disk-pecking. On another level the response class may be defined as "a peck on a disk following the preceding peck by at least t seconds". In this case the strengthening effect of reinforcement implies the differentiation of long disk-peck interresponse times (IRTs) and thus a decrease in the rate of disk-pecking per se. The two effects of reinforcement are in a sense compatible, since strengthening of a response class usually implies differentiation of the class with respect to the reinforced properties of the response. A distinction may be made however when reinforcement is presented differentially with respect to a property of a larger response class and responses within the subclass defined by the reinforced values of the property increase in frequency while other responses of the class do not.

Researchers have tended to concentrate on one or the other of the two effects of reinforcement and have frequently ignored an apparent incompatability. Reinforcement of responses with long IRTs cannot produce both high rates of responding and long IRTs simultaneously. According to Skinner's discussion of response differentiation, if the IRT is a differentiable property of responding, then the reinforcement of long IRTs should increase the frequency of long IRTs and decrease the rate of responding defined without reference to the IRT. This effect would be in opposition to the strengthening effect on the larger response class which would produce an increase in the rate of responding. Historically, the two effects of reinforcement have been studied independently, leading to the parallel development of two hypotheses concerning the determination of response rate. One hypothesis, which for reasons which will become apparent may be called the "relative law of effect", emphasizes the presumed strengthening effect of reinforcement. The other, which may be called "interresponse time reinforcement theory", emphasizes the presumed differentiating effect of reinforcement on IRTs. The evidence in support of these hypotheses is briefly reviewed below, beginning with the "strengthening" interpretation, which has a longer history in the literature.

The two potential effects of reinforcement on response rate described above can lead to confusion in the usage of the term "reinforcement". For this reason reinforcement is defined in this thesis as an operation, not as a process or result. The operation is the presentation of a stimulus known to increase the frequency of behavior it follows. In the particular cases described in the thesis, this stimulus is grain presented to hungry pigeons.

Both the relative law of effect and IRT reinforcement theory concern wider ranges of phenomena than are considered here. The region of interest for this thesis, and an area of mutual concern to the two hypotheses, includes the effects of simple schedules of reinforcement on response rate. By simple schedules is meant situations in which only one response is measured and a reinforcement criterion is stated in terms of the number of responses or the time between reinforcements.

Those schedules specifying the time between reinforcements are of particular pertinence to this thesis because of the relationships between responding and reinforcement they generate.

The Relative Law of Effect

Although Skinner (1938) recognized both the strengthening and differentiating effects of reinforcement on responding, he dealt chiefly with the strengthening effect. His analysis of the strengthening of responding by reinforcement emphasized the importance of response rate in the measurement of reinforcement effects, as illustrated by the following passage (1938, p. 58):

> the main datum to be measured in the study of the dynamic laws of an operant is the length of time elapsing between a response and the response immediately preceding it or, in other words, the rate of responding.

Although this passage equates IRTs and response rate, Skinner's emphasis on rate is apparent from his statement that "the rate of responding is the principal measure of the strength of an operant" (p. 58). Reinforcement increases the rate of emission of a response by increasing its strength.

The analysis of reinforcement effects on behavior begun by Skinner in 1938 was extended in Ferster and Skinner (1957) to a variety of schedules of reinforcement presentation. This latter work discussed the multiple determination of response rate by differentiating and strengthening processes, but again emphasized the role of reinforcement in strengthening responding. Studies by Catania and Reynolds (1968) focussed on the interval-based reinforcement schedules described by Ferster and Skinner and provided parametric data on the relationship between reinforcement rate and response rate. Response rate was found to increase monotonically with reinforcement rate. The more frequently a response was reinforced, the stronger it became.

The relationship between response and reinforcement rates on simple reinforcement schedules has been neatly summarized by Herrnstein (1970). Herrnstein dealt with a wide range of reinforcement schedule phenomena and based his analysis upon data from situations in which several responses were concurrently reinforced. His formulation provides a succinct statement of the strengthening effect of reinforcement on responding and is used here as a convenient description of relationships obtained with interval-based reinforcement schedules. It is also an hypothesis about the determination of response rate since it ascribes controlling properties to reinforcement rate.

Herrnstein's hypothesis is that response rate is determined by the rate of reinforcement delivered for that response relative to the total rate of reinforcement occurring in the situation. It is important to note that the relationship is between response rate and obtained reinforcement rate since the utility of the hypothesis is limited by the fact that it specifies a relationship between two dependent variables. The hypothesis may be stated in symbolic form as:

$$P = \frac{kR}{R + R_o} \qquad (1)$$

where P is response rate, R is the reinforcement rate for response P, R_o is an empirical constant representing the reinforcement rate for all other behavior occurring in the situation, and k is another empirical constant representing the maximum rate of occurrence of the response. Response rate is thus proportional to its reinforcement rate relative to the total reinforcement rate in the situation. For this reason the hypothesis has been called the "relative law of effect".

IRT Reinforcement Theory

Catania and Reynolds (1968) discussed their interval schedule data in terms of an analysis based on the differential reinforcement of IRTs. They pointed out that the interval schedules they used differentially reinforced IRTs because longer IRTs were more likely to be reinforced than were shorter ones. The longer an animal waited from the last response, the greater was the probability of the next response being reinforced. The relationship between response rate and reinforcement rate could be accounted for on the basis of reinforcement of longer IRTs on schedules with lower reinforcement rates. As Catania and Reynolds noted, this IRT differentiation analysis of their data is consistent with the response strengthening analysis discussed above. Discrimination of the two effects of reinforcement is not possible with this type of data. Another class of experiment is required.

According to IRT reinforcement theory, the time between consecutive occurrences of a response -- the IRT -- is a differentiable property of the response terminating the IRT. The selection of various values of the IRT by reinforcement determines the emission of future IRT values. Response rate is then determined, at least in part, by the rate of responding at the time reinforcement occurs. Two principal classes of experiment provide a basis for the IRT reinforcement hypothesis. In both cases reinforcement is made contingent upon IRTs differentially according to the length of the IRT, although the manner in which this contingency is specified differs. Also in both cases one usually observes an increase in the frequency of the more frequently reinforced IRTs. However, both classes of experiment fail to discriminate the contribution to response rate of strengthening and differerentiating effects of reinforcement. Since the recults of these experiments have been taken as evidence for the differentiating effect of reinforcement, it is necessary to go into some detail of the procedures to explain how they fail to discriminate differentiating from strengthening effects.

In the more easily implemented of the two classes of experiment, reinforcement occurs only after IRTs which are temporally longer than some value t. Reinforcement is not presented after IRTs shorter than t. This class of experiment may be referred to as IRT > t (inter-response time greater than t) schedules of reinforcement presentation. A very large body of data obtained from animals responding on IRT > t schedules has been collected (Kramer & Rilling, 1970). The general result has been that as the t value of the schedule is increased and longer IRTs are reinforced, the response rate decreases and the relative frequency distribution of IRTs increases in the region around t. Although consistent with the IRT reinforcement hypothesis, the observation of longer IRTs on IRT > t schedules with larger t values is not sufficient to establish the control of IRTs and response rate through differential reinforcement of IRTs, independent of changes in the overall reinforcement rate. Indeed, reinforcement rate decreases as t increases in the precise manner required by the relative law of effect to produce the observed decrease in response rate.

Data from a study by Staddon (1965) demonstrate the confounding of IRT reinforcement and reinforcement rate effects which occurs on IRT > t reinforcement schedules. Pigeons were exposed to IRT > t schedules with t values ranging from 5 to 30 seconds. As shown in Figure 1-1a, larger t values produced lower rates of responding. However, as shown in Figure 1-1b, larger t values were also associated with lower reinforcement rates. The IRT > t class of

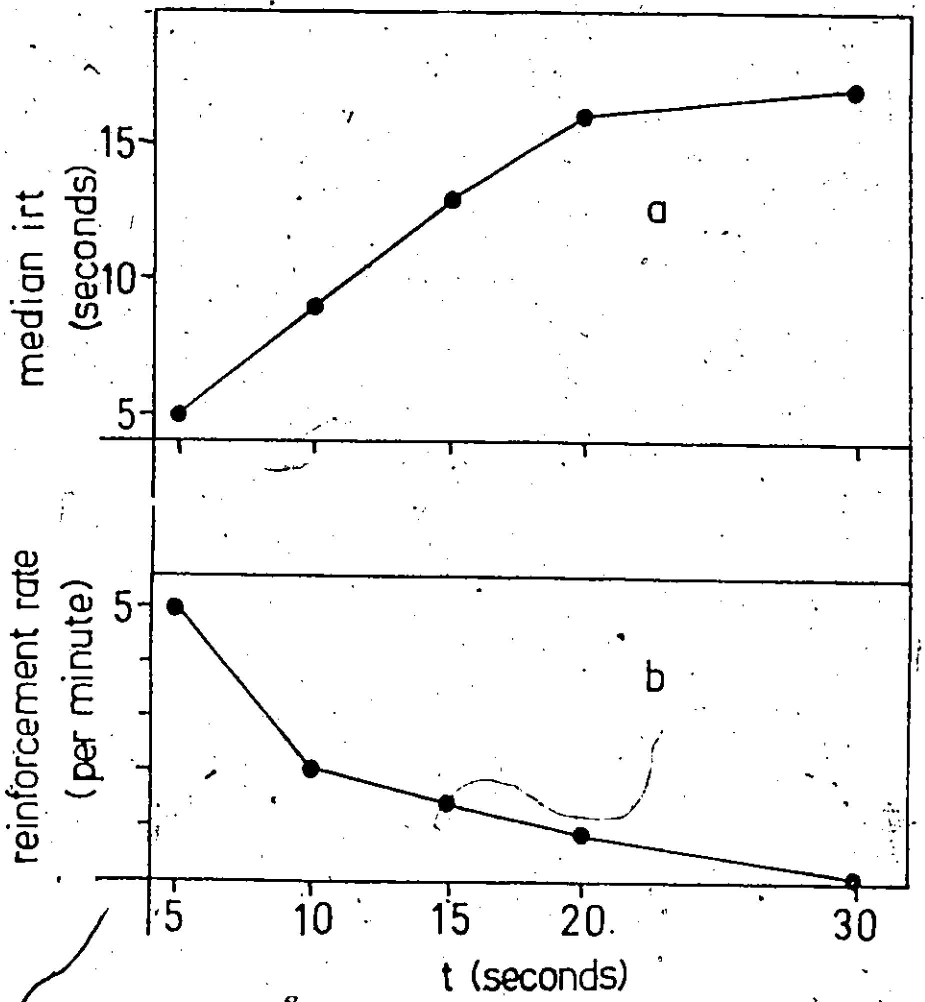

Figure 1-1. IRT and reinforcement rate data obtained on IRT > t reinforcement schedules. Redrawn from Staddon (1965).

experiment does not allow an analysis of the relative contribution of strengthening and differentiating effects of reinforcement, since they are confounded in the procedure.

A second class of IRT reinforcement experiments also involves the differential reinforcement of IRTs according to length. The "synthetic variable interval schedules" originated by Anger (1956) and extended by Shimp (1973) were designed to retain some control over reinforcement rate while accomplishing this differential reinforcement. However, although the interaction between the animal's behavior and the experimenter's schedule of IRT reinforcement is more complex than in the IRT > t case, reinforcement rate still depends on the animal's behavior. Shimp noted the poor control of reinforcement rate on these schedules but dismissed it as an unimportant variable in the determination of response rate. His argument was based on data from a situation bearing little resemblance to the synthetic variable interval schedule (Shimp, 1972) and is thus not convincing.

The synthetic variable interval schedule used by Anger was an attempt at mimicking the distribution of those IRTs which are reinforced on an interval schedule. Anger first obtained the relative frequency distribution of IRTs reinforced on a standard variable interval schedule. He then reinforced IRTs of various length classes with probabilities corresponding to those actually obtained on the variable interval schedule. By waiting for the ocurrence ~~of an~~ IRT in a particular length class before presenting the reinforcement arranged by the interval component of the schedule, he was able to control the relative frequency distribution of IRTs which were reinforced. Since the resultant schedule was a variable interval schedule with an added IRT contingency, it is called a synthetic variable interval schedule.

The variable interval part of the synthetic schedule purportedly allows the reinforcement rate to be better controlled than it typically is with IRT > t schedules, but the reinforcement rate must still vary with the IRT reinforcement function. The schedule must wait longer for rarer IRTs, producing a dependency between the reinforcement rate and the IRT reinforcement function. The differential reinforcement of long, and thus rare, IRTs should be associated with lower reinforcement rates than the differential reinforcement of more frequently occurring IRTs. As in the case of IRT > t schedules, reinforcement rate and IRT differentiation are confounded.

One of Shimp's (1973) experiments demonstrates the limitations of synthetic variable interval schedules in the analysis of a response rate determination. Hungry pigeons were trained to peck at a disk for food reinforcement. A mean two-second interval rendered the variable interval component of the schedule superfluous, since reinforcement was actually delivered on the average every 60 to 120 seconds (the mean reinforcement interval or RI). The principal determiner of the obtained reinforcement rate was the second, IRT reinforcement, component of the schedule in interaction with the pigeon's behavior.

The IRT reinforcement component of the synthetic schedule determined which of ten half-second IRT classes between 1.0 and 6.0 seconds would be followed by the reinforcement enabled by the interval programmer. The IRT reinforcement function varied from a nondifferential 0.1 probability of choosing an IRT class to a maximally differential function of 0.0222x - 0.0222, where x is the IRT class number between 1 and 10. In the maximally differential case, the probability of choosing an IRT class for reinforcement increased from 0% for IRTs between 1.0 and 1.5 seconds to 20% for IRTs between 5.5 and 6.0 seconds. The 2% to 9% of IRTs not between 1.0 and 6.0 seconds were ignored in both the procedure and the analysis. Shimp found that as longer IRTs were more frequently reinforced, the pigeons produced a greater relative frequency of longer IRTs.

As the reinforcement function changed from nondifferential reinforcement of IRTs to differential reinforcement of longer, less frequent, IRTs, the reinforcement frequency probably decreased. A decrease in reinforcement frequency with greater reinforcement of long IRTs could account for much of the 60 second spread in the RIs obtained in Shimp's study. The reinforcement schedule simply had to wait longer for a longer, less frequent, IRT than for a shorter, more frequent one. Shimp did not present data indicating changes in RI with changes in IRT reinforcement, so the foregoing interpretation is largely speculative.

The only conclusion possible from data obtained on synthetic variable interval schedules is that either reinforcement rate or IRT differentiation produced changes in response rate. No judgement concerning the differential contribution of these factors can be made with data from this paradigm.

Richardson (1973) employed variable interval schedules in yet another manner in order to substantiate the effectiveness of IRT reinforcement in modulating response rate. He exposed pigeons and rats to standard IRT > 15 seconds reinforcement schedules and recorded the series of RIs produced by the animals as their behavior interacted with the schedule. These series of RIs formed the basis for variable interval schedules used in the second phase of his experiment. Richardson found that response rates on the variable interval schedules were higher than the response rates on the IRT > 15 seconds schedule, even though the mean RI was nearly the same in both cases.

Richardson's experiment provided good evidence that IRT differentiation can affect response rate even when reinforcement rate is controlled. However, since only one reinforcement rate per subject was used, and since this rate was determined by the subject, changes in IRT differentiation effectiveness with reinforcement rate could not be assessed. Also, there was no nondifferential reinforcement condition with which to compare the differentiation. The IRT > t schedule data were compared with data from variable interval schedules, which present reinforcement differentially with respect to

IRTs in the sense that longer IRTs are more likely to be reinforced (Catania & Reynolds, 1968). Effects strictly attributable to reinforcement rate could not be determined from Richardson's data. The experiment stands primarily as a crucial demonstration of the efficacy of IRT reinforcement in changing response rate in the absence of concomitant changes in reinforcement rate. This result casts doubt on the sufficiency of a strengthening effect of reinforcement in the detemination of response rate, but does not indicate the relative contribution of differentiating and strengthening effects.

Synthetic variable interval schedules and IRT >t schedules fail to discriminate between strengthening and differentiating effects of reinforcement. Richardson's (1973) comparison of variable interval and IRT > t schedules provides evidence for a differentiating effect independent of a strengthening effect but does not provide an account of the relative size of these effects. What is required is a procedure which allows the independent manipulation of reinforcement rate and IRT reinforcement across a range of values of these variables.

Percentile Reinforcement Schedules

A technique for the independent manipulation of IRT reinforcement and reinforcement rate is provided by a class of paradigms called percentile reinforcement schedules (Platt, 1973). When the IRT is the behavioral unit of interest, percentile schedules allow the experimenter to present reinforcement differentially after IRTs according to their lengths while maintaining a constant RI.

The major difference between percentile IRT schedules and the IRT schedules previously discussed is that the absolute value of the IRT reinforcement criterion on percentile schedules changes as the animal's behavior changes. With IRT > t and synthetic variable interval schedules reinforcement is always specified for an absolute, unchanging class of IRT lengths, independent of the animal's behavior. It is this independence of the animal's behavior and the experimenter's reinforcement criterion which produces the dependence of reinforcement rate on behavior. Percentile schedules change the criterion as the behavior changes and thus fix the criterion to the behavior by defining the criterion relative to a behavioral scale.

Repeated occurrences of a behavior will have a distribution of values of any measure of behavior. The IRT is a fundamental measure of behavior which can be used to exemplify the rationale behind the percentile reinforcement schedule. A sequence of ten instances of the behavior provides a sample of nine IRTs. According to a theorem of order statistics (Smith, 1953), each of these nine IRTs estimates a decile point of the population distribution from which they were drawn. The goodness of this estimate depends upon an assumption of random independent sampling of the IRT from the population distribution. Some studies of IRT reinforcement on IRT > t schedules have suggested the presence of sequential dependencies between IRTs, thus violating this assumption (e.g., Weiss, Laties, Siegel, & Goldstein, 1966). For the purposes of experimental control, the requirement of random independent sampling can be circumvented by using a sample size large enough to average out any short-term sequential dependencies yet small enough to accurately track long-term changes in the mean IRT. Appropriate choice of the sample size can thus overcome this theoretical difficulty and produce adequate predictability of percentile points (Alleman & Platt, 1973).

Over a large number of IRT distribution samples, 10% of the IRTs produced by the animal will fall within the intervals demarcated by the nine sample IRTs, as these are continuously resampled. An IRT can be ranked relative to the sample distribution of IRTs and thus assigned a percentile value relative to the absolute time lengths of the sample IRTs. The percentile ranking is the basis of the behavioral scale which allows control of the relation between behavior and reinforcement parameters.

Figure 1-2a illustrates the percentile reinforcement control procedure as applied to IRTs. A distribution of the animal's most recent IRTs is obtained. The new IRT to be considered for reinforcement is compared to the IRTs in this distribution and given a percentile ranking according to its length relative to the lengths of the other IRTs. Let us assume that the experimenter desires to differentially reinforce long IRTs while maintaining a constant 5% of responses reinforced. The dashed line in Figure 1-2a indicates the 95th percentile point of the IRT distribution. By reinforcing an IRT if and only if its length exceeds the length intersected by this line, the reinforcement probability will be held at 5%. Equivalently, if the percentile ranking of the new IRT is less than 95%, it is not reinforced.

The percentile method of determining reinforcement does not depend upon the shape of the IRT distribution, since percentile points do not depend upon distribution parameters. As the distribution of recent IRTs changes, the percentile cutoff for reinforcement shifts relative to the time scale, maintaining a constant relation

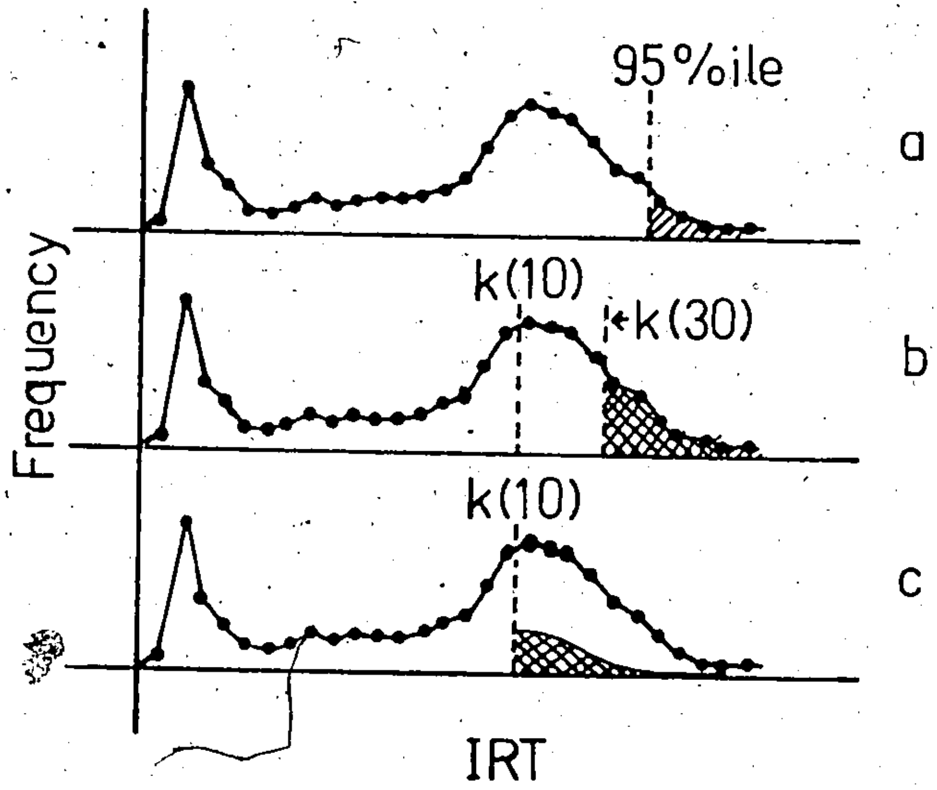

Figure 1-2. Percentile reinforcement of IRTs, showing three different methods of determining the reinforcement criterion, indicated by the dotted line. In part a, all IRTs greater than the 95th percentile are reinforced. In part b, 10-second and 30-second interval Selectivities are indicated. In part c, a 10-second Selectivity with a 33% random ratio superimposed is indicated by the cross-hatched area.

between the reinforcement criterion and the animal's behavior in the sense that a reinforced IRT is always greater than 95% of recently emitted IRTs.

Extrapolating this specific example to the general case, let m be the number of past IRTs with which the reinforcement ranking is to be accomplished. The m IRTs mark off m+1 intervals on the IRT continuum. If the current IRT has to exceed k of these IRTs to be reinforced, then the probability of reinforcement, P, is given by:

$$P = 1 - \frac{k}{m+1} . \qquad (3)$$

In the previous example, with P = 5%, if 19 IRTs provided the sample against which the current IRT were ranked (m = 19), then an IRT would have to exceed 18 of these IRTs to be reinforced. The reinforcement criterion could be placed anywhere in the distribution, between any two percentile points or off either end of the distribution. In each case, the probability of reinforcement would be determined by the mean percentage of IRTs falling within the reinforced interval.

The specific case of percentile schedules in which reinforcement probability is held constant while IRTs are differentially reinforced was investigated by Alleman and Platt (1973). These investigators employed P values from 5% to 50%, differentially reinforcing IRTs which were either longer than or shorter than recently emitted IRTs.

They found that at P values of 5% and 10%, reinforcing longer IRTs produced longer IRTs than reinforcing shorter IRTs even though reinforcement probability was the same in both cases. Of course as the response rate decreased when longer IRTs were reinforced, the reinforcement rate also decreased.

IRT Reinforcement with Controlled Reinforcement Interval

The foregoing exposition of percentile reinforcement procedures dealt with the control of reinforcement probability during IRT differentiation experiments. Probability control is the most direct application of percentile schedules since these schedules specify reinforcement criteria in terms of percentages of behavioral output. However, the primary interest in the present context is the control of reinforcement interval during IRT differentiation. The application of percentile schedules to this problem requires further development of the mathematics involved in a free-responding situation.

A given response rate multiplied by a specified reinforcement probability determines the reinforcement rate. The animal determines the response rate and the experimenter may control either the reinforcement probability or reinforcement rate, the remaining variable being thus determined by a function of the other two. This relation between response and reinforcement rates and reinforcement probability can be expressed as a relation between mean interresponse time (IRT), mean reinforcement interval (RI), and reinforcement probability (P) given by:

$$\text{IRT} = \text{RI} \times \text{P} . \qquad (4a)$$

Verbally, the relation states that the mean time between responses is equal to the mean time between reinforcements multiplied by the probability of reinforcement.

In order to hold RI constant, reinforcement probability must be allowed to vary with the mean IRT. Rearranging Equation 4a, we find that the reinforcement probability must vary in direct proportion with the mean of past IRTs as given by:

$$\text{P} = \text{IRT}/\text{RI} . \qquad (4b)$$

If we specify the RI and use the mean of the animal's last m IRTs to estimate the population mean IRT, the probability of reinforcement is determined. By varying P to accomodate changes in the mean IRT during an experimental session, the mean RI can be held constant. As the mean of recent IRTs increases, the reinforcement probability is adjusted upwards, and vice versa. The method of determining reinforcement for a response summarized by Equation 4b was used in the baseline conditions of the present experiments. Since the reinforcement probability depended upon the mean of recent IRTs, and the current IRT was not averaged into this mean, reinforcement was nondifferential with respect to the length of the current IRT.

In order to differentially reinforce IRTs while maintaining a constant RI, both Equations 3 and 4b must be satisfied. Equation 3 specifies reinforcement probability when IRTs are being differentially reinforced and Equation 4b specifies reinforcement probability when RI is being held constant. Solving these two equations simultaneously gives a value for k, the number of IRTs the current IRT must exceed to be reinforced:

$$k = (m + 1) \times (1 - \mathrm{IRT}/\mathrm{RI}). \qquad (5a)$$

Changing k as the mean IRT changes allows both maintenance of the RI and the differential reinforcement of IRTs, since only IRTs which exceed k of the m recent IRTs are reinforced in this procedure.

For any given mean IRT, Equation 5a specifies a larger value of k for larger values of RI. This means that at lower densities of reinforcement, the differential reinforcement of IRTs will be more selective, as it is applied to a smaller portion of the IRT frequency distribution. Selectivity is defined by the RI in Equation 5a, which determines the range of IRT values to be reinforced. Since the RI and Selectivity (Sel) can differ as described below, Equation 5a should be written:

$$k = (m + 1) \times (1 - \mathrm{IRT}/\mathrm{Sel}). \qquad (5b)$$

As an example of how selectivity affects the range of reinforced IRT values, Figure 1-2b presents an IRT distribution with a reinforcement cutoff determined by a programmed RI of 10 seconds, k(10). For the same distribution, an RI of 30 seconds will produce a higher cutoff, k(30), since a larger number of IRTs must be exceeded by the current IRT. The k(30) value defines a higher selectivity than the k(10) because reinforcement is applied to a smaller range of the IRT distribution. The reinforced IRTs in the 30 second case are more removed from the main body of the IRT distribution than they are in the 10 second case.

Selectivity is distinct from RI, which simply determines the frequency with which behavior attains a reinforcement criterion. Selectivity defines a range of IRT values for reinforcement while RI is independent of IRT value. By varying the proportion of IRTs within the selectivity-determined range which are reinforced, RI and selectivity can be independently manipulated. The technique is illustrated in Figure 1-2c. A 10-second Sel in Equation 5b determines the k(10) value as before. However, only a random one-third of the IRTs selected for reinforcement actually receive reinforcement (the cross-hatched area in Figure 1-2c). In this manner a 30-second RI is obtained while the selectivity of reinforcement is the same as for a 10-second RI. Comparing the cross-hatched areas in parts b and c of Figure 1-2, it is clear that a k(30) criterion results in more extreme differential reinforcement than the K(10) criterion at the same RI. It is important to note that the k values, and the proportion of reinforced responses they produce, vary with the mean IRT. For this reason the selectivity is specified in terms of the invariant time values used in Equation 5b to determine these k values.

Percentile reinforcement of IRTs with reinforcement interval control is a tool which can be used to pry apart the effects of reinforcement rate and IRT differentiation on response rate. The four experiments making up the body of this thesis put this tool to use. Experiment 1 compares the effects of maximally selective reinforcement of long and short IRTs to nonselective reinforcement over a range of RI values from 10 to 120 seconds. Experiment 2 extends the results for long IRT reinforcement to a 300-second RI. Experiment 3 describes the effects of changing selectivity with a constant RI and changing RI with a constant selectivity. Experiment 4 further analyses the effects of RI and selectivity in a search for interaction between them.

General Methodology

The four experiments reported here all employed percentile reinforcement schedules for the differential reinforcement of IRTs in the context of controlled mean reinforcement intervals. Other similarities in the procedures of the four experiments are detailed below.

Subjects

The subjects were 32 experimentally naive Carneau and White King pigeons obtained from the Palmetto Pigeon Plant, South Carolina. They were maintained at approximately 80% of their free-feeding weights by supplementary rations of mixed grain given at the end of each session in the home cage. Sixteen pigeons were used in Experiment 1. Four of these were used in Experiment 2 and another four in Experiment 3. An additional 16 pigeons were the subjects of Experiment 4.

Apparatus

Four Lehigh Valley Electronics 3-key pigeon operant chambers were used. Only the center disk was used and it was illuminated by a white light during the experimental sessions. Reinforcement consisted of 3-second access to mixed grain presented in the food hopper while the key light was turned off. A 28-volt, 100-milliampere houselight illuminated the chamber throughout the session. The scheduling of stimuli and the accumulation of data were accomplished by means of a laboratory computer. A minimum opening of the disk microswitch for 0.1 seconds was required before a subsequent peck on the disk was recognized as a separate response. During Experiment 1, all IRTs were recorded on paper tape with 0.1 second accuracy. In Experiments 2, 3, and 4 the last three sessions of Baseline and the last six sessions of Differential Phases were so recorded, while during nonterminal sessions only session summary statistics were acquired.

Procedures

Pretraining. The pigeons were first trained to eat from the food hopper and to peck the illuminated disk in the chamber. Training to eat from the hopper involved the presentation of the hopper at variable intervals with a mean interval of 90 seconds between presentations. The hopper remained raised until the pigeon had intercepted a photo-beam across the hopper opening for a cumulative 3 seconds.

Simultaneously with hopper training, an 8-second illumination of the pecking disk preceded each hopper presentation on the 90-second mean interval schedule. This pairing of disk-light and food presentation constituted an "auto-shaping" procedure (Brown & Jenkins, 1968) which induces disk-pecking in pigeons. Thirty such pairings were administered in each session. This pretraining continued until the pigeon pecked the disk at least seven times in a single session.

IRT List. The computer maintained a list of the IRTs most recently emitted by each pigeon. This list was carried over from one session to the next to provide continuity between sessions. IRTs totalling twice the programmed RI value were kept in the list and oldest IRTs were deleted as the addition of new IRTs increased the total IRT time in the list beyond this amount. By updating this list of IRTs as a sample of the IRT population, there would be on the average two reinforced IRTs in the list, since it spanned two average reinforcement intervals. The list size was chosen to be large enough to allow a good prediction of the IRT population distribution, yet small enough to follow trends in the distribution as the mean IRT changed.

Baseline Phases. The decision routine determining reinforcement during Baseline Phases was described previously and is summarized by Equation 4b. RI is the only parameter specified in this routine and the probability of reinforcement varied inversely with the mean of list IRTs, independently of the current IRT.

Differential Phases. During Differential Phases reinforcement was determined using Equation 5b. The RI was set by the experimenter and the IRT and m were determined by the mean IRT in the stored IRT list. The value of k was then computed from Equation 5b. The parameter k is the number of IRTs in the list which the current IRT must exceed to be reinforced. In Experiment I "exceed" meant either "be less than" or "be greater than". In the other experiments only the "greater than" direction was used. The current IRT was then compared to all the IRTs in the list. If it exceeded k or more of the IRTs, it was designated a criterial IRT, otherwise no action in the chamber was taken. In either case the current IRT was entered into the list and as many of the oldest IRTs were removed as possible without reducing the sum of the IRTs in the list below twice the RI.

If the current IRT met the reinforcement criterion, the random ratio parameter was checked. In Experiments 1 and 2 this parameter was always 100%. In the other two experiments it varied from 8% to 100%. The random ratio parameter determined what percentage of criterial IRTs was actually reinforced. In this manner the selectivity of the differential reinforcement could be varied from the maximum possible for a given RI down through less selective values. For example, with a Selectivity of 30 seconds and a random ratio of 25%, only one-fourth of the criterial IRTs would be reinforced and the RI would be 120 seconds. The RI and the Selectivity determined the schedule. In Experiments 3 and 4 where these two parameters differed, the schedules are noted as

RI : Selectivity, both in seconds.

The random ratio routine selected a number from a pseudo-random number generator and compared it to the requested ratio. If the selected number was smaller than the requested ratio, reinforcement ? occurred, otherwise not.

General. Sessions occurred daily, six or seven days per week. A session terminated when 30 reinforcements had been delivered (20 reinforcements in Experiment 2). Differential Phases were usually 30 sessions in length while Baseline Phases varied from 10 to 22 sessions. These phase lengths ensured a comparatively stable group mean IRT with respect to the preceding fluctuations.

Chapter 2

Experiment 1

Reinforcement Rate and Selective Reinforcement of Long and Short Interresponse Times

Rationale

The first question broached by the present series of experiments concerns the reinforceability of IRTs in the absence of changes in reinforcement rate. The converse question was also of interest: what effect does reinforcement rate have on IRTs in the absence of differential reinforcement of IRTs?

In order to answer these questions, Experiment 1 varied RI over the range of values typically employed in experiments investigating response rate changes on simple variable interval schedules (Catania & Reynolds, 1968). Four values of RI between 10 and 120 seconds were used with a group of four subjects at each of the four values. Nondifferential Baseline Phases provided an answer to the second of the above questions, the independent effect of RI on mean IRT.

The subjects were exposed to differential reinforcement of long or short IRTs during two Differential Phases. The use of percentile reinforcement schedules allowed this differential reinforcement of IRTs to occur without changes in the RI. Within each RI condition three different reinforcement conditions -- short IRT reinforcement, long IRT reinforcement, and nondifferential reinforcement -- permitted an assessment of the unconfounded effects of IRT reinforcement on response rate.

Procedure

Sixteen pigeons were exposed to reinforcement schedules with RIs of 10, 30, 60, and 120 seconds. There were four pigeons in each RI group. Nondifferential Baseline Phases alternated with Differential Phases during which long or short IRTs were selectively reinforced on a percentile schedule. Half of each RI group was exposed to long IRT reinforcement in the first Differential Phase and short IRT reinforcement in the second Differential Phase. The other half of each group received the reverse order of treatments. Selectivity was the maximum allowable under the RI in effect, in accord with Equation 5b.

The first Baseline Phase included two sessions at a 10-second RI for all groups. The 30-, 60-, and 120-second groups then received one session at a 30-second RI. This was followed by one session at a 60-second RI for the 60- and 120-second groups and a 120-second RI session for the 120-second group. This phase continued for a total of 22 sessions so all groups had at least 18 sessions at the appropriate RI.

The Differential Phases consumed 30 sessions each and the last two Baseline Phases were 16 sessions each. The order of conditions is summarized for each pigeon in Table 2-1.

Subject Number	Reinforcement Interval (seconds)	First Baseline Phase	First Differential Phase	Second Baseline Phase	Second Differential Phase	Third Baseline Phase
1,2	10	-	S	-	L	-
3,4	10	-	L	-	S	-
5,6	30	-	S	-	L	-
7,8	30	-	L	-	S	-
9,10	60	-	S	-	L	-
11,12	60	-	L	-	S	-
13,14	120	-	S	-	L	-
15,16	120	-	L	-	S	-

Table 2-1. Sequence of treatments for subjects of Experiment 1. L indicates long IRTs reinforced, S indicates short IRTs reinforced.

Results

The principal results of Experiment 1 are shown in Figure 2-1 which presents the changes in session mean IRT for each pigeon during the five phases of the experiment. In each group the data of the two subjects first receiving long IRT differentiation are plotted in circles while the data of the other two are indicated by squares. Dotted lines also differentiate the data of pigeons receiving short IRT differentiation during the two Differential Phases. As is obvious in this figure, in all four RI conditions the session mean IRT increased when long IRTs were selectively reinforced and then decreased upon return to the nondifferential baseline condition. Further, the extent of IRT change increased across groups as the RI and Selectivity values increased concomitantly.

To Summarize the end-of-phase results, data from the last three sessions of Baseline Phases and the last six sessions of Differential Phases were averaged. The higher number of responses and lower between-session variability during the shorter Baseline Phases dictated the need for a smaller number of sessions in the summary statistics. Similarly the last six sessions of the more variable Differential Phases provide a reasonable sample of the behavior occurring at the end of these phases.

Table 2-3 presents summary data from the three Baseline Phases of Experiment 1, including the mean IRT, the mean reinforced IRT, the mean obtained RI, the mean post-reinforcement pause, and the mean proportion of reinforced responses. All of these measures

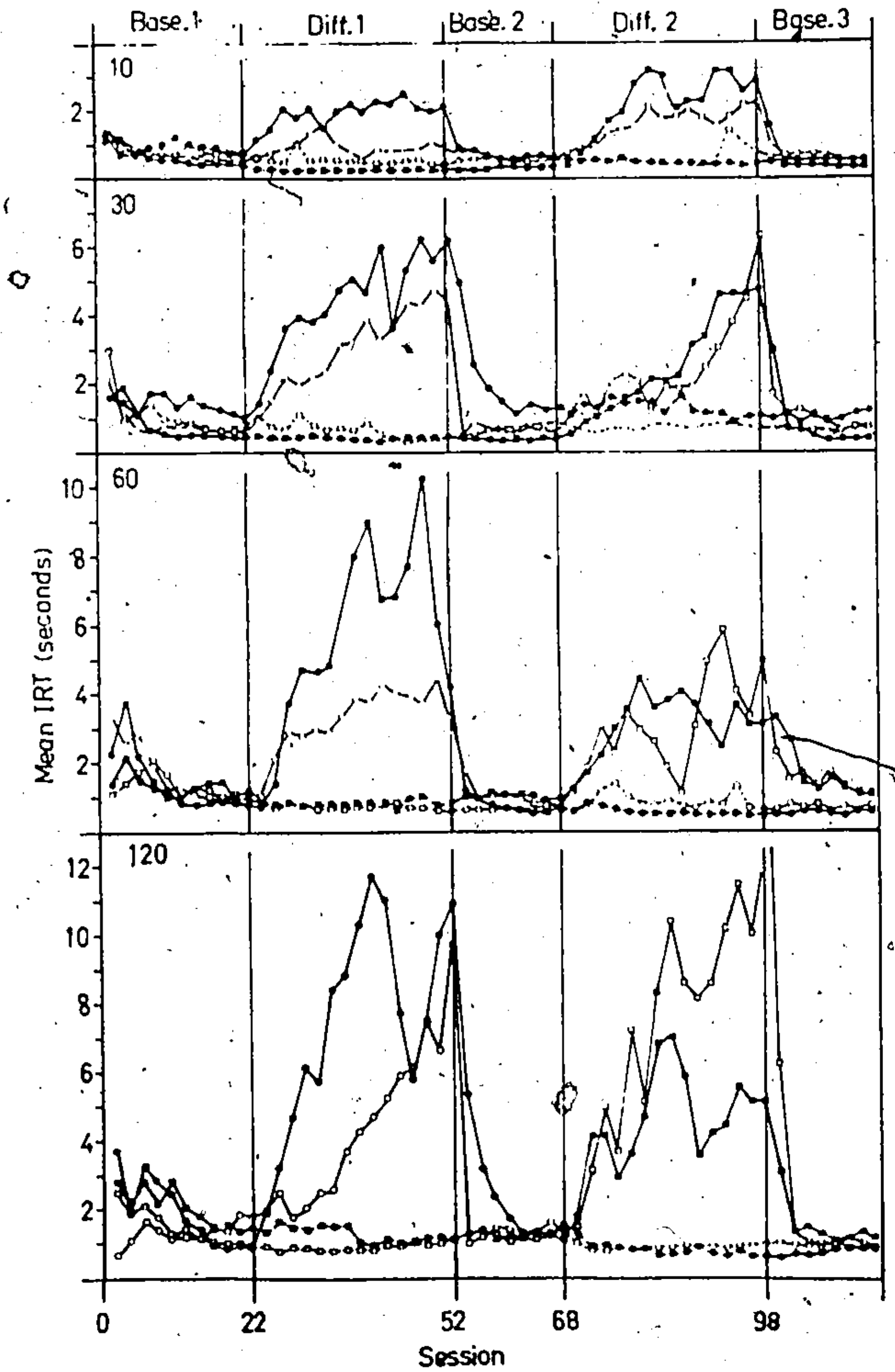

Figure 2-1. Mean session IRTs of subjects in Experiment 1, plotted in two-session blocks, for Baseline (Base.) and Differential (Diff.) Phases. The first and second numbered subjects in each group are plotted in squares (filled and open respectively) and the third and fourth in circles (filled and open respectively). The RI (and Selectivity) values are indicated in the upper left hand corners.

Reinforcement Interval	Baseline Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion	Post-Reinforcement Pause
10	1	0.70	0.76	10	0.072	1.72
	2	0.61	0.59	10	0.062	1.65
	3	0.56	0.56	9	0.061	2.52
	Mean	0.62	0.64	10	0.065	1.96
30	1	0.82	0.81	32	0.026	2.60
	2	0.84	0.78	28	0.030	2.36
	3	0.81	0.86	30	0.027	3.13
	Mean	0.82	0.82	30	0.028	2.70
60	1	1.01	0.95	58	0.018	2.80
	2	0.82	0.80	61	0.014	4.62
	3	0.91	0.97	61	0.015	2.55
	Mean	0.91	0.91	60	0.016	3.32
120	1	1.34	1.39	118	0.011	17.88
	2	1.37	1.33	111	0.012	15.95
	3	1.07	1.01	114	0.010	17.02
	Mean	1.26	1.24	114	0.011	16.95

Table 2-2. End-of-phase data for the three Baseline Phases of Experiment 1. All time data are in seconds.

were quite comparable across the three Baselines. For this reason it was considered justifiable to use just the IRTs of the first Baseline Phase in the more extensive data analyses below.

The group mean IRTs produced at the end of Baseline and Differential Phases are presented in Figure 2-2. The twelve-fold increase in RI from 10 to 120 seconds produced a small increase in the mean baseline IRT from 0.62 to 1.26 seconds; $F\ (3,12) = 3.94$; $p < 0.05$. When short IRTs were differentially reinforced (indicated by unfilled circles in the figure), mean IRTs somewhat shorter than baseline IRTs were emitted ; $F\ (1,12) = 7.48$; $p < 0.05$. The effect was apparently constrained by the amount of IRT range available for change from the already quite short baseline IRTs. The largest effect apparent in Figure 2-2 is that produced by differential reinforcement of long IRTs (filled circles in the figure). During this condition the mean IRT was from 3.3 times (at the 10-second RI) to 6.6 times (at the 120-second RI) as long as the baseline mean IRT. Although the effect did not increase monotonically with RI because of the similar IRTs obtained at 30 second and 60 second RIs, the overall trend was towards a greater difference in mean IRTs at higher RI and Selectivity values. The effect of long IRT reinforcement is quite apparent in the figure; $F\ (1,12) = 74.11$; $p \leq 0.001$, and the differences between groups, caused by the RI and Selectivity differences, are also obvious; $F\ (3,12) = 12.12$; $p < 0.001$. The interaction of these two variables was also significant; $F\ (3,12) = 6.75$; $p < 0.01$, substantiating the

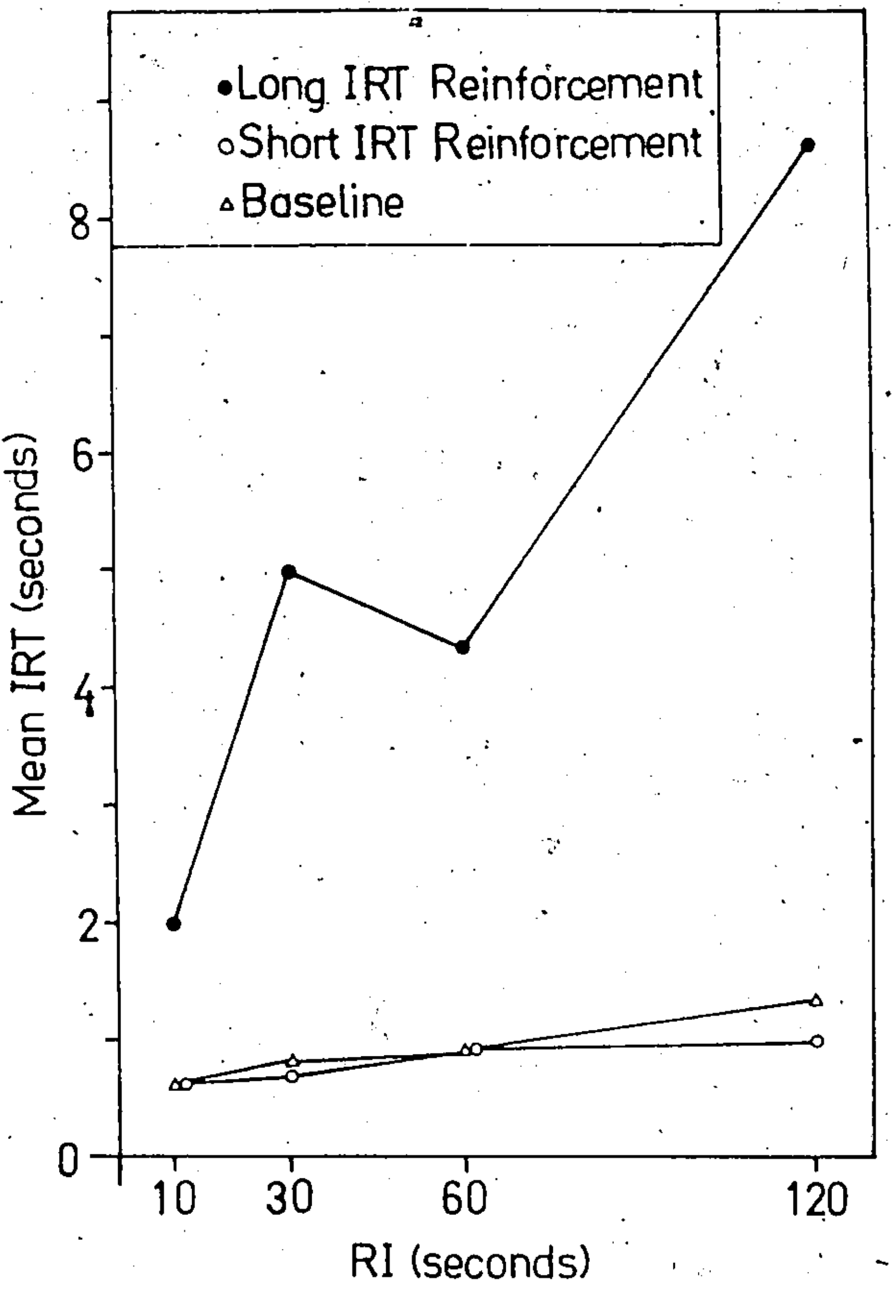

Figure 2-2. End-of-phase group mean IRTs from Experiment 1.

apparent trend toward greater effects of selectivity at higher RI and Selectivity values.

Another means of observing the changes in IRTs with conditions is provided by the relative frequency distributions of IRTs, which are only roughly summarized by the mean IRTs presented in Figure 2-2. Figure 2-3 presents these distributions for each pigeon for the last three sessions of the first Baseline and the last six sessions of Differential Phases for long IRT reinforcement only. Distributions obtained during short IRT reinforcement did not differ greatly or consistently from baseline IRT distributions and are not shown. The effects of differential reinforcement of long IRTs on the IRT distributions are clear: long IRTs increased in frequency while short IRTs decreased proportionately. The Differential Phase distributions were generally bimodal or greatly skewed toward long IRTs while the Baseline Phase distributions were unimodal with a single large peak at short IRT values. As the IRT and Selectivity values of the schedules increased, the upper peak or long tail of the Differential Phase distributions moved to higher values. The effect of RI on the Baseline Phase distributions was not so clearcut, although there was some suggestion of greater positive skewing of the distributions with increasing RI.

The differences in mean IRT shown in Figure 2-2 were associated with differences in the reinforcement of IRTs and in RI. The manner in which the differential reinforcement of IRTs changed with the differentiation and RI treatment is depicted

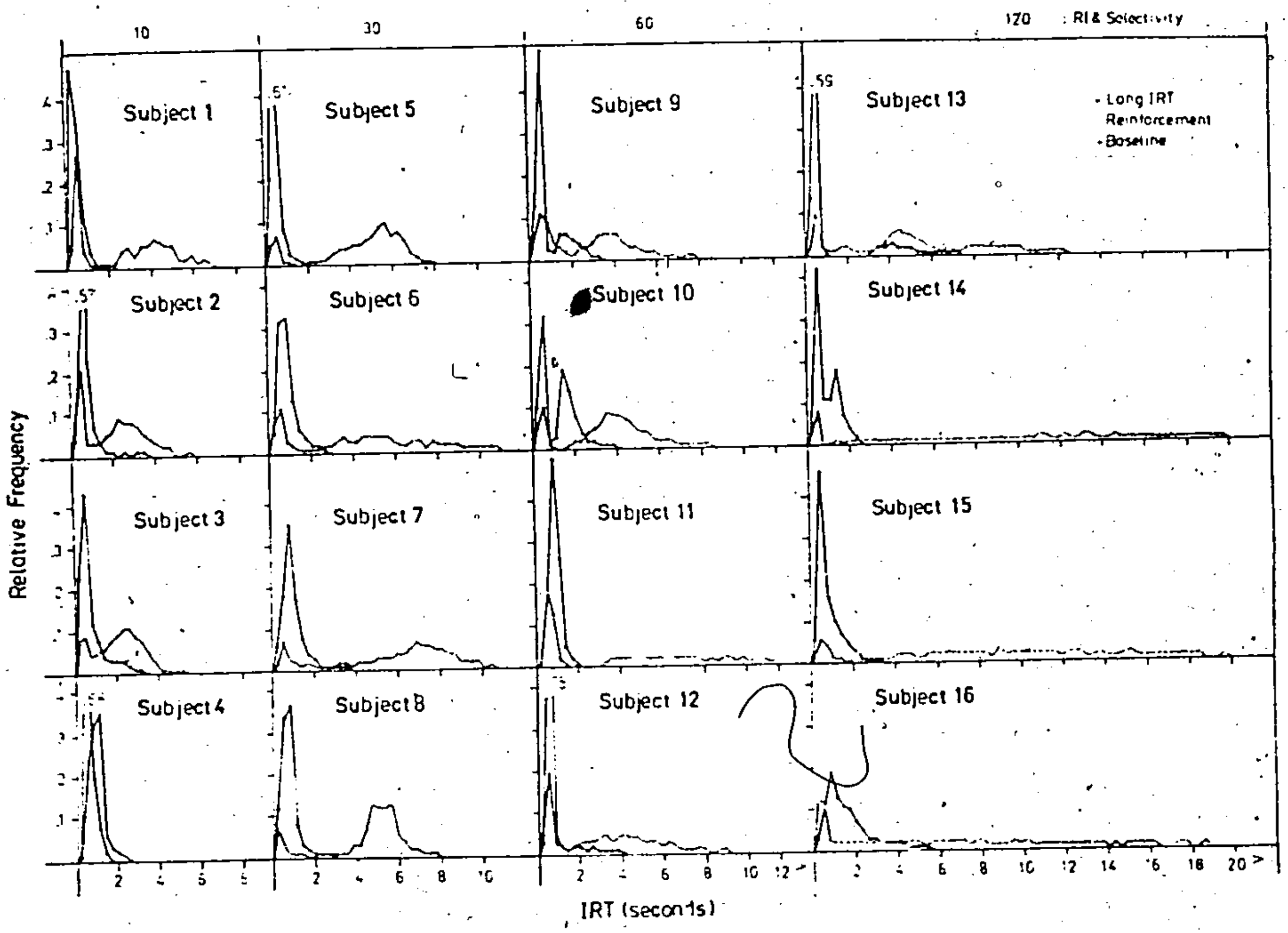

Figure 2-3. Relative frequency distributions of IRTs for the subjects of Experiment 1 during the first Baseline Phase and the long IRT reinforcement Differential Phase.

in Figure 2-4, which presents the mean reinforced IRT as a function of treatment condition. During differential reinforcement of long IRTs, the mean reinforced IRT increased with the RI and Selectivity values. The difference between the mean reinforced IRT and the mean IRT also increased, from 1.8 seconds at the 10-second values to 13.5 seconds at the 120-second values. More extreme differential reinforcement thus occurred along with longer mean IRTs. On the other hand, during short IRT reinforcement, larger differences between mean reinforced IRTs and mean IRTs occurred along with longer mean IRTs. The more extreme differential reinforcement did not produce shorter IRTs. During baseline conditions, the mean reinforced IRTs and the mean IRTs were approximately equal, as expected in this nondifferential condition.

Table 2-3 presents the RIs obtained during the experiment for each differentiation and RI condition. The data show that obtained RIs were slightly longer during long IRT reinforcement and slightly shorter during short IRT reinforcement, than they were during Baseline. This result is more clearly shown by another datum in the table, which also indicates the basis for this bias in the mean RI. The proportion of the obtained RIs shorter than 0.2 of the programmed RI are listed for the various differentiation and RI conditions. The proportion of RIs expected to fall within this interval of an exponential distribution of RIs is 0.181.

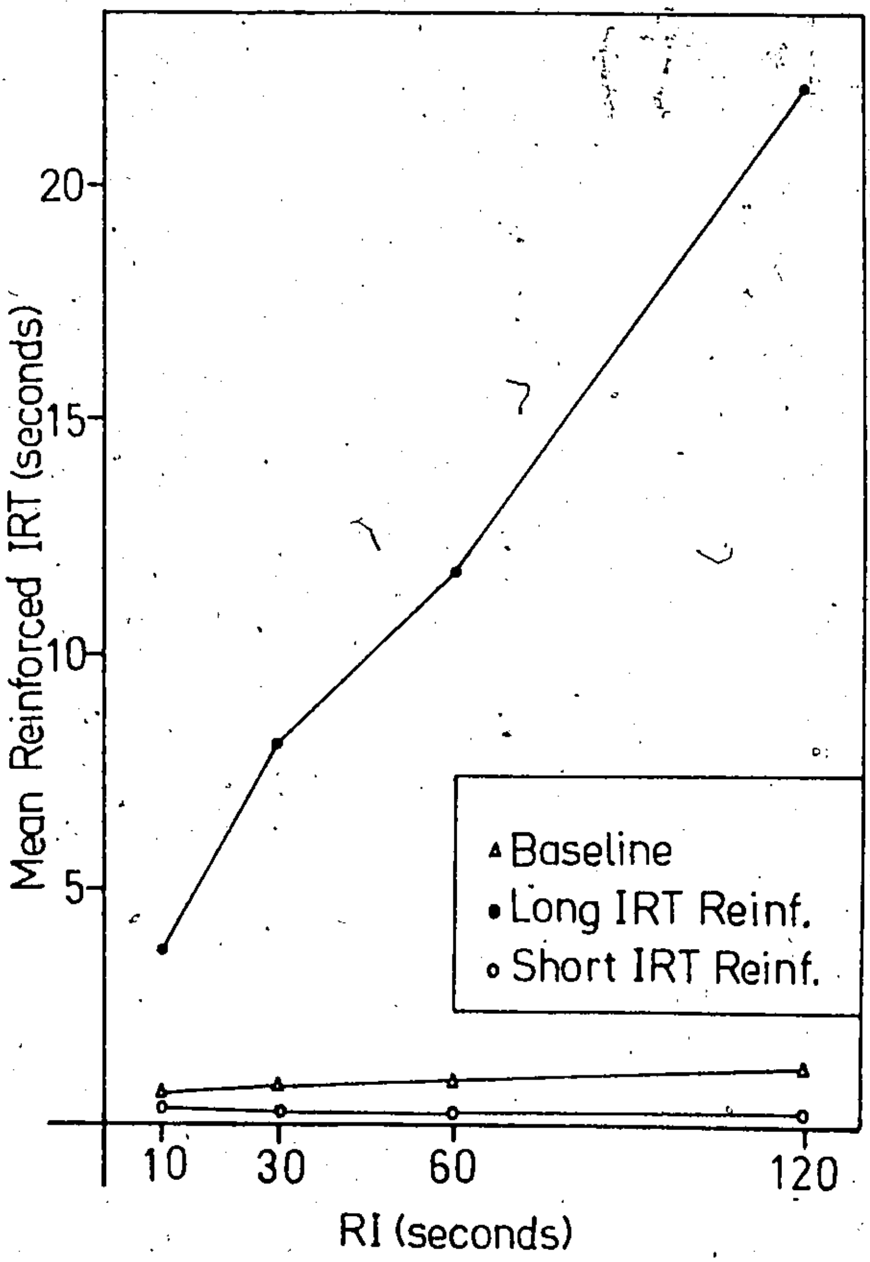

Figure 2-4. End-of-phase group mean reinforced IRTs from Experiment 1.

	Differentiation Condition					
	Baseline		Long IRTs		Short IRTs	
Reinforcement Interval	RI	0.2	RI	0.2	RI	0.2
10	9.9	0.170	10.8	0.022	9.9	0.239
30	30.1	0.172	31.6	0.030	29.2	0.287
60	59.8	0.181	63.9	0.111	59.0	0.243
120	118	0.155	129	0.108	122	0.216

Table 2-3. The obtained RI and the proportion of RIs shorter than 0.2 of the expected RI. See text for explanation. All values in seconds.

This proportion was closely approximated during Baseline Phases. However, during long IRT reinforcement, fewer than the expected proportion of RIs were this short while during short IRT reinforcement more than the expected proportion fell within this short RI range. Possible reasons for this bias in the control procedure are discussed below.

A reinforcement parameter of interest from the standpoint of the determination of response rate is the proportion of responses followed by reinforcement. In the present experiment, as Equation 4b states, this proportion was determined by the RI and the mean IRT. The change in IRT as the reinforced response proportion changed is presented in Figure 2-5. With the RI controlled, as the mean IRT increased, the proportion of reinforced responses also increased.

The time from termination of a reinforcement presentation to the first response is called the post-reinforcement pause. The pause did not enter into the IRT reinforcement decision or into the RI computation routines. This datum is presented in Table 2-4. During long IRT reinforcement the pause increased regularly with the RI and Selectivity. During Baseline and short IRT reinforcement there was no effect on the pause from 10 seconds to 60 seconds. There was a large increase in pause length in the 120 second group. Except for this latter group the pause was longer during long IRT reinforcement than during Baseline and short IRT reinforcement. The latter two conditions did not differ in pause length.

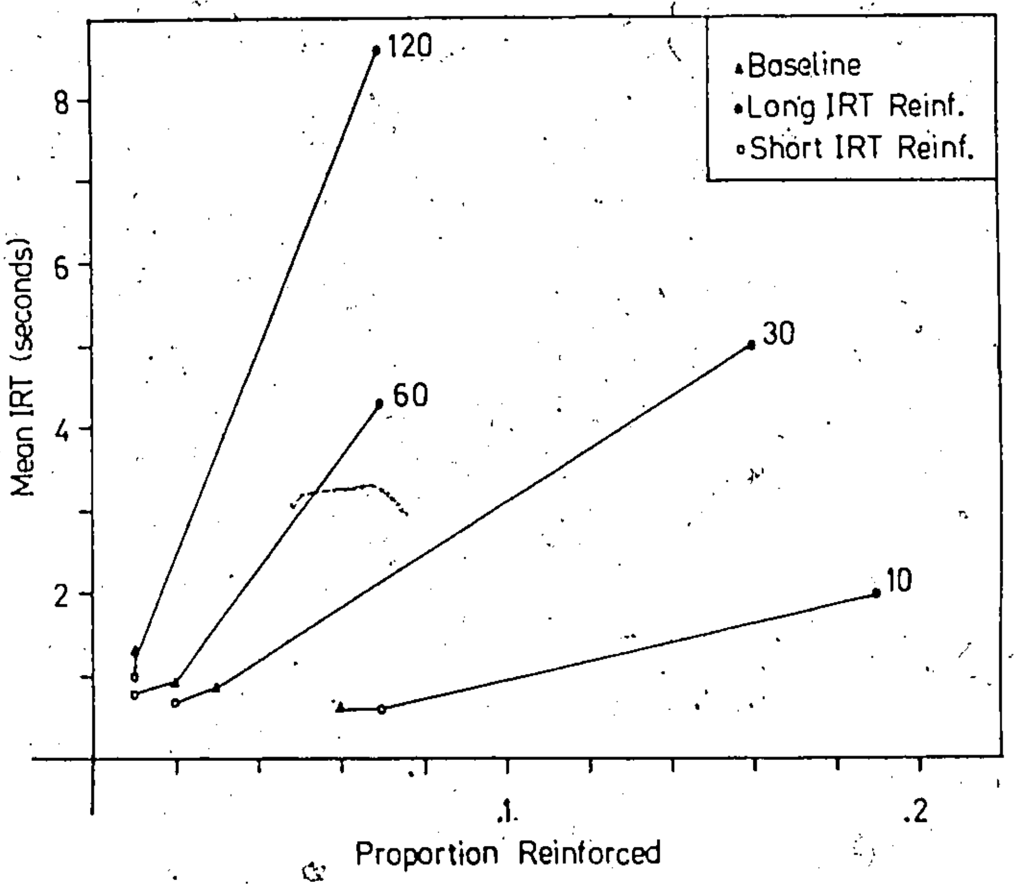

Figure 2-5. Proportion of responses reinforced plotted against mean IRT and RI. RI (and Selectivity) values are indicated by numbers to the right of the appropriate curve in the figure.

Reinforcement Interval	Baseline 1	Differentiation Condition Long IRTs	Short IRTs
10	1.72	4.60	1.76
30	2.60	7.82	2.14
60	2.80	9.33	1.93
120	17.88	18.75	25.75

Table 2-4. Post-reinforcement pause lengths obtained in Experiment 1. All times are in seconds.

A final datum of interest is the change in response rate between reinforcements. This datum illustrates local effects of reinforcement on response rate. In Figure 2-6 the response rate during fixed intervals of time after reinforcement is presented. The basic interval is one-fourth of the RI and response rates are presented for successive intervals after reinforcement up to twice the RI. Only responses prior to the next successive reinforcement are counted, so the number of observations decreased as the time from reinforcement increased. The rate in each interval was computed relative to the mean rate across all eight intervals, where each interval was equally weighted in the computation of the mean. For most groups during Baseline Phases and short IRT reinforcement, there was a transient high response rate immediately after reinforcement followed by a decline to a steady level. During long IRT reinforcement, the response rate immediately after reinforcement was in most cases quite low, and subsequently increased to a steady level.

Discussion

This experiment provides unambiguous support for the existence of an IRT reinforcement process independent of the effects of reinforcement rate on IRTs. Differentially reinforcing long IRTs produced longer IRTs, and differentially reinforcing short IRTs produced shorter IRTs, compared to IRTs which occurred when reinforcement was presented without regard to the length of the IRT. These

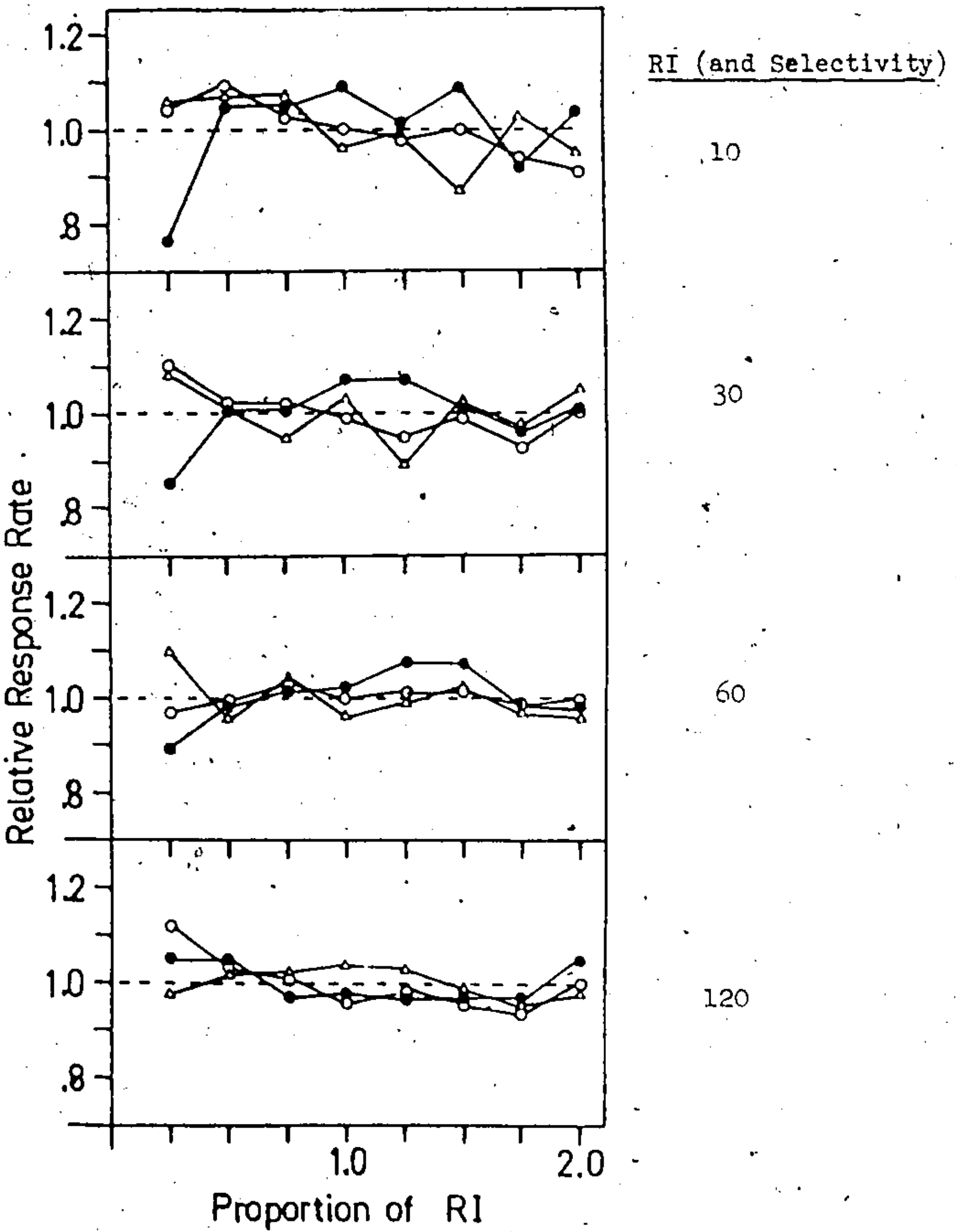

Figure 2-6. Response rate relative to overall response rate in intervals following reinforcement presentation. Triangles indicate Baseline Phase data and open and filled circles indicated long and short IRT reinforcement respectively.

effects occurred within four different RI conditions where the mean RI was held constant at 10, 30, 60, or 120 seconds, indicating some generality of the phenomenon over the range of RI values typically employed in experiments on response rate determination.

The comparability of the present results with other results in the literature is indicated by Figure 2-7. In this figure response rate versus reinforcement rate data obtained by Catania and Reynolds (1968) on variable interval reinforcement schedules are plotted along with the present baseline data. These data were made comparable by adding the post-reinforcement pauses to the total session times and then computing overall rates of responding and reinforcement. The procedures used by Catania and Reynolds in their study, other than the scheduling of the variable interval, were quite similar to those employed here so the comparison has some utility. As the figure shows, the baseline conditions of the present study produced response rates reasonably close to those obtained by Catania and Reynolds, although generally higher. The generally elevated response rates in the present study may reflect procedural differences. More interestingly, they may be due to the lack of IRT differentiation in the baseline condition as compared to that occurring on standard variable interval schedules, since the response rate differences in the present study reflect effects of reinforcement rate in the absence of concomitant IRT differentiation. As described earlier, standard variable interval schedules differentially reinforce longer IRTs in the sense that longer IRTs are more likely to be reinforced.

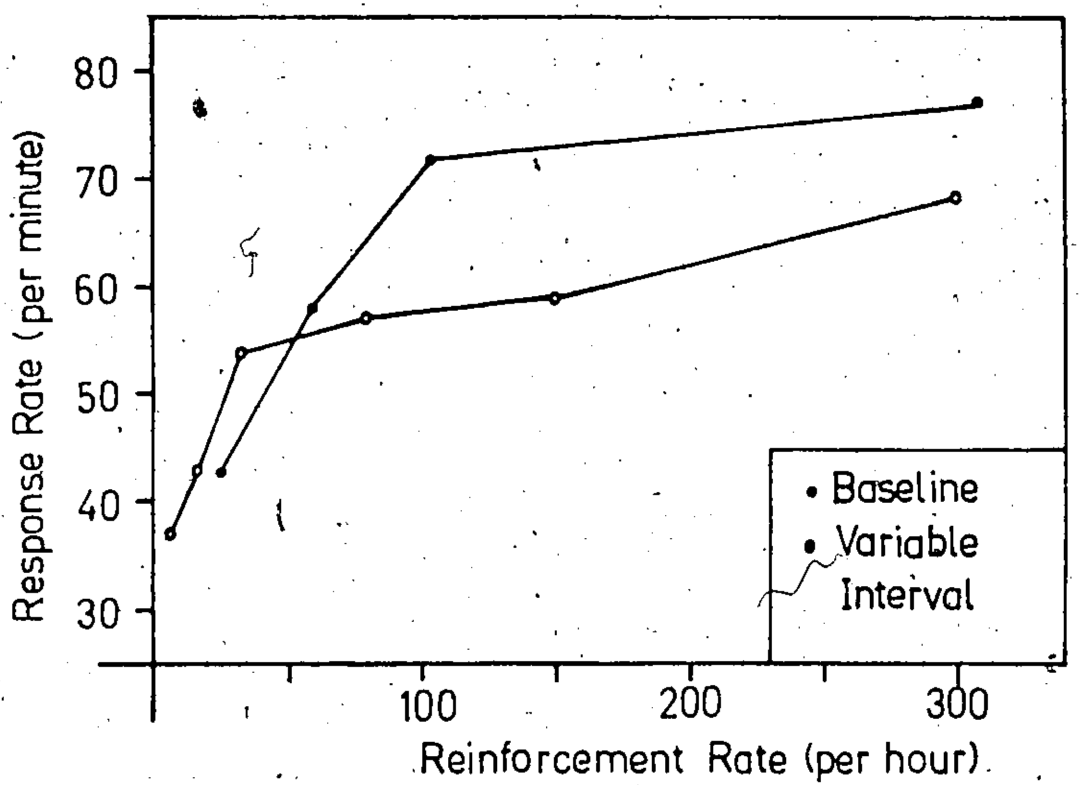

Figure 2-7. Response rate as a function of reinforcement rate for the Baseline Phase of Experiment 1. Variable interval schedule data are redrawn from Catania and Reynolds (1968) for comparison.

Although the IRT reinforcement function on variable interval schedules is continuous rather than a discrete step function as in the percentile reinforcement procedures used in the present experiment, it may be an important determiner of the response rate on variable interval schedules.

The change in IRT from Baseline Phases to long IRT reinforcement increased as the RI and Selectivity values of the schedule increased. Since Selectivity was maximal for all RI values, it was perfectly confounded with RI. It is clear that within a RI and Selectivity condition, maximal Selectivity produced a large change in mean IRT relative to baseline. This result, in combination with the very small effect of RI on baseline IRTs, makes it likely that selectivity is primarily responsible for the large IRT differences across groups during long IRT reinforcement.

Differentially reinforcing short IRTs produced small though statistically significant changes in emitted IRTs. The small size of the change is probably due to the small range of IRT values in which change could occur. The baseline IRTs were already quite close to the shortest IRTs that could be emitted. Differentially reinforcing short IRTs shifted the IRT distributions towards lower values, but there was not much room in which this shift could occur. Since short IRT differentiation effects were constrained by the range of possible effects, the other three experiments investigated only differentiation of long IRTs. Long IRT differentiation allowed greater sensitivity of the measurement scale to effects both of

IRT selection and reinforcement rate.

The condition-dependent bias observed in the RI distribution was reflected in a very small difference in the mean RIs for the three differentiation conditions. Although these RI differences were in the appropriate direction for strengthening effect accounts, their magnitude could not have produced the large differences in mean IRTs, nor even have contributed significantly to these differences. Since a twelve-fold increase in RI produced a mere doubling of the mean IRT, the maximal 9% difference in mean RI could not have had much effect.

Nonetheless, from a programmatic point of view the source of these RI distribution biases is important. The explanation for the short RI deficit during long IRT reinforcement is obvious. The shortest RI was limited by the shortest reinforceable IRT. When only long IRTs were chosen for reinforcement, the shortest of these was the minimum possible RI. After effective long IRT reinforcement, this lower limit on the RI necessitated a deficit of short RIs. Although the bias in mean RI had little or no effect on the mean IRT, this deficit of short RIs may have had effects on the lengths of IRTs immediately after reinforcement. As noted by Catania and Reynolds (1968), short RIs, or equivalently, the local rate of reinforcement immediately after reinforcement, can produce significant effects on local rates of responding. The addition of short RIs to a variable interval reinforcement schedule increases the rate of responding immediately after reinforcement without affecting the overall rate of responding to any great extent. Similar effects on local response rate were found in the present experiment as seen in Figure 2-6.

The bias in the RI distribution for short IRT reinforcement is not so easily explained. The sequential IRT data presented in Figure 2-6 suggest one possible explanation. The relatively shorter IRTs immediately after reinforcement were more likely to be reinforced than the later, longer IRTs. There would thus be a local elevation in the probability of reinforcement immediately after the occurrence of reinforcement. This short-term trend in IRTs might have been sufficient to produce the observed excess of short RIs.

The approximately linear increase in post-reinforcement pause with increasing RI during long IRT reinforcement occurred in the absence of any reinforcement of the pause. The increase in pause length resembled the increase in IRT with RI (Figure 2-2), although the absolute values of the pause were about twice as long as the mean IRT values. The increase in post-reinforcement pause with increasing RI also resembled the reinforced IRT function (Figure 2-4), in absolute values as well as in general shape. The mean pause was slightly longer than the mean reinforced IRT at the 10-second RI, slightly shorter at the 120-second RI, and increased monotonically in between. Clearly, entering the pause into the reinforcement decision routine on an equivalent basis with IRTs would have led to an extreme bias in the RI distributions towards short RIs and clusterings of reinforcements. The pause is operationally distinct from an IRT since it is the interval between an experimenter-determined event and a subject-determined event, rather than between two subject-determined events. However, the similarity between the pause's relationships with reinforcement and the reinforcement - IRT relationships suggests an underlying commonality in the two intervals. An increase in the frequency of nonpecking behavior, caused by reinforcement of long IRTs and independent of the event initiating the interval, may provide the basis for this commonality.

Strength of responding has been found in other studies to be affected by reinforcement rate and by the proportion of responses reinforced. Response strength, indexed by response rate, increases with both of these variables. The present experiment not only found response rate changes with a constant reinforcement rate, it also produced some interesting relations between response rate and reinforcement probability. The data of Figure 2-5 show that within an RI condition, higher reinforcement probabilities occurred along with longer IRTs and lower response rates. This result is opposite to that observed on other types of schedules which lack control of the reinforcement interval (e.g., Sidley & Schoenfeld, 1964).

Chapter 3

Experiment 2

Differential Reinforcement of Long IRTs with 300 second RI and Selectivity

Rationale

The mean IRT function presented in Figure 2-2 left open the possibility of further increase in mean IRT with larger values of RI and Selectivity. The variable interval schedule data presented in Figure 2-7 also suggested that further decreases in reinforcement rate below the thirty reinforcements per hour used in Experiment 1 might produce further decreases in response rate. To establish whether the range of RI values in Experiment 1 covered the range of effects of RI on response rate, a RI of 300 seconds was used in Baseline and long IRT reinforcement conditions in Experiment 2.

A subsidiary interest in the present study was suggested by the data of Table 2-3. The bias in the RI distributions obtained in Experiment 1 decreased with increasing RI. An even larger RI might avoid this minor bias altogether.

Procedure

After Experiment 1 the four pigeons in the 120 second group were run for several sessions at a RI of 120 seconds in preparation for another manipulation. This manipulation was discarded in favor of the present experiment and the RI was increased to a value of 300 seconds with Baseline conditions still in effect. Two sessions at each of 180-second and 240-second RIs were administered before exposing the birds to the 300-second RI. The number of reinforcements delivered per session was reduced to 20 for the entire experiment. Nine sessions of Baseline with a 300-second RI were followed by 32 sessions of long IRT reinforcement with a Selectivity criterion of 300 seconds. The Differential Phase was then followed by a return to Baseline, still at the 300-second RI, for an additional 14 sessions.

Results

Data for the last three sessions of Baseline Phases and the last six sessions of the Differential Phase are presented in Table 3-1. The 120-second data produced by this group in Experiment 1 are included for comparison. Both Baseline and Differential Phase IRTs were somewhat shorter at the 300 second value than at the 120 second value. The mean reinforced IRT during the Differential Phase at 300 seconds was 19.7 seconds longer than the mean emitted IRT. This constituted more extreme differential reinforcement than that which occurred during long IRT reinforcement at 120 seconds. In the latter case the reinforced IRT was only 13.5 seconds larger than the mean emitted IRT. Even though the differential reinforcement was more extreme at 300 seconds, the resultant IRTs were similar at both values.

Condition	Sessions	Mean IRT	Mean Reinforced IRT	Obtained RI	Proportion of RIs less than 0.2xRI
Experiment 1					
Baseline	16	1.3	1.4	118	0.155
120:120	30	8.6	22.1	130	0.108
Experiment 2					
Baseline 1	9	1.2	1.2	362	0.204
300:300	32	7.9	27.6	283	0.163
Baseline 2	14	1.4	1.5	365	-

Table 3-1. End-of-phase data for Experiment 2. Data for these same subjects in Experiment 1 are presented for comparison. All time data are in seconds.

As in Experiment 1, the mean RI differed between Differential and Baseline Phases. However, the bias in this experiment was in a direction opposite to that obtained in Experiment 1, so that large differences in Baseline and Differential Phase IRTs occurred in opposition to this RI bias. Also, the dearth of short RIs was well remedied in this experiment. During reinforcement of long IRTs, RIs less than 60 seconds in length were 0.163 of the total RIs, only 0.018 short of the expected proportion of RIs of this length.

Discussion

Increasing the RI and Selectivity values two-and-a-half times over the maximum value used in Experiment 1 had no effect on baseline IRTs or on the efficacy of differential reinforcement in changing the length of IRTs. This result suggests that Experiment 1 covered the effective range of RI values. This conclusion is somewhat attenuated by the within-subjects nature of the comparison since all the other RI comparisons of Experiment 1 were made between groups of subjects. It is possible that the long prior exposure of the subjects of Experiment 2 to 120-second RI schedules may have biased the results of Experiment 2. Two arguments counter this suggestion however. The IRTs of the subjects of Experiment 2 were still quite labile and susceptible to changes in the reinforcement contingencies as evidenced by the large effect of differential reinforcement on the mean IRTs. Secondly, the rather large change in RI produced no effect on IRTs, not even a trend in the appropriate direction.

The experiment also dispenses with the RI bias problem of Experiment 1 since a similar IRT result occurred in the presence of an opposite bias in the mean RI during long IRT reinforcement. This result obviates any possibility of the IRT differences observed within the RI conditions of Experiment 1 having been due to biases in the interval-control procedure.

Chapter 4

Experiment 3

Varying Selectivity of Differential Reinforcement of Long IRTs with Constant Reinforcement Interval

Rationale

Experiment 1 found a large increase in mean IRT as the RI and Selectivity parameters increased from 10 seconds to 120 seconds during differential reinforcement of long IRTs. The large effect of differential reinforcement at constant RI, and the small effect of RI during nondifferential Baseline Phases, supported the inference that differential reinforcement was the principal factor in determining the large mean IRT increase with increasing RI and Selectivity values. Experiment 3 tested this inference by observing the effects of different Selectivity values with a constant RI in effect.

Procedure

The four pigeons of the 10-second RI group of Experiment 1 were exposed to three different conditions of differential reinforcement. All conditions had an overall RI of 120 seconds. Baseline was the usual nondifferential condition. The 120:10 condition used a Selectivity criterion of 10 seconds (in Equation 5) but reinforced only one-twelfth of the criterial IRTs, thus producing a 120-second RI. The 120:120 condition was the same as in Experiment 1 where the Selectivity and RI were equal at 120 seconds.

Because of the possibility of attenuation of the effects of the 120:120 condition by treatment order, two consecutive sequences of conditions were used. A 13-session Baseline Phase was followed by 32 sessions of 120:10 and 32 sessions of 120:120. Sixteen sessions of 120:10 terminated this sequence. A 10-session Baseline Phase was then followed with an immediate shift to a 30-session 120:120 Differential Phase, without the interpolated 120:10 condition as in the first sequence.

Results

The changes in the group mean IRTs across sessions during Differential Phases is presented in Figure 4-1. Figure 4-1a shows IRT changes during the first 120:10 and 120:120 conditions and includes the data obtained at 10 seconds during Experiment 1 for purposes of comparison. Figure 4-1b shows IRT changes during the second 120:10 and 120:120 conditions and includes the 120 second data of Experiment 1 (Subjects 13 through 16) for purposes of comparison.

The change from the 120-second Baseline to the 120:10 condition produced a small, gradual increment in the mean IRT (see Figure 4-1a). Increasing the Selectivity to 120 seconds produced a further increase in the mean IRT. Return to the 10- second Selectivity was

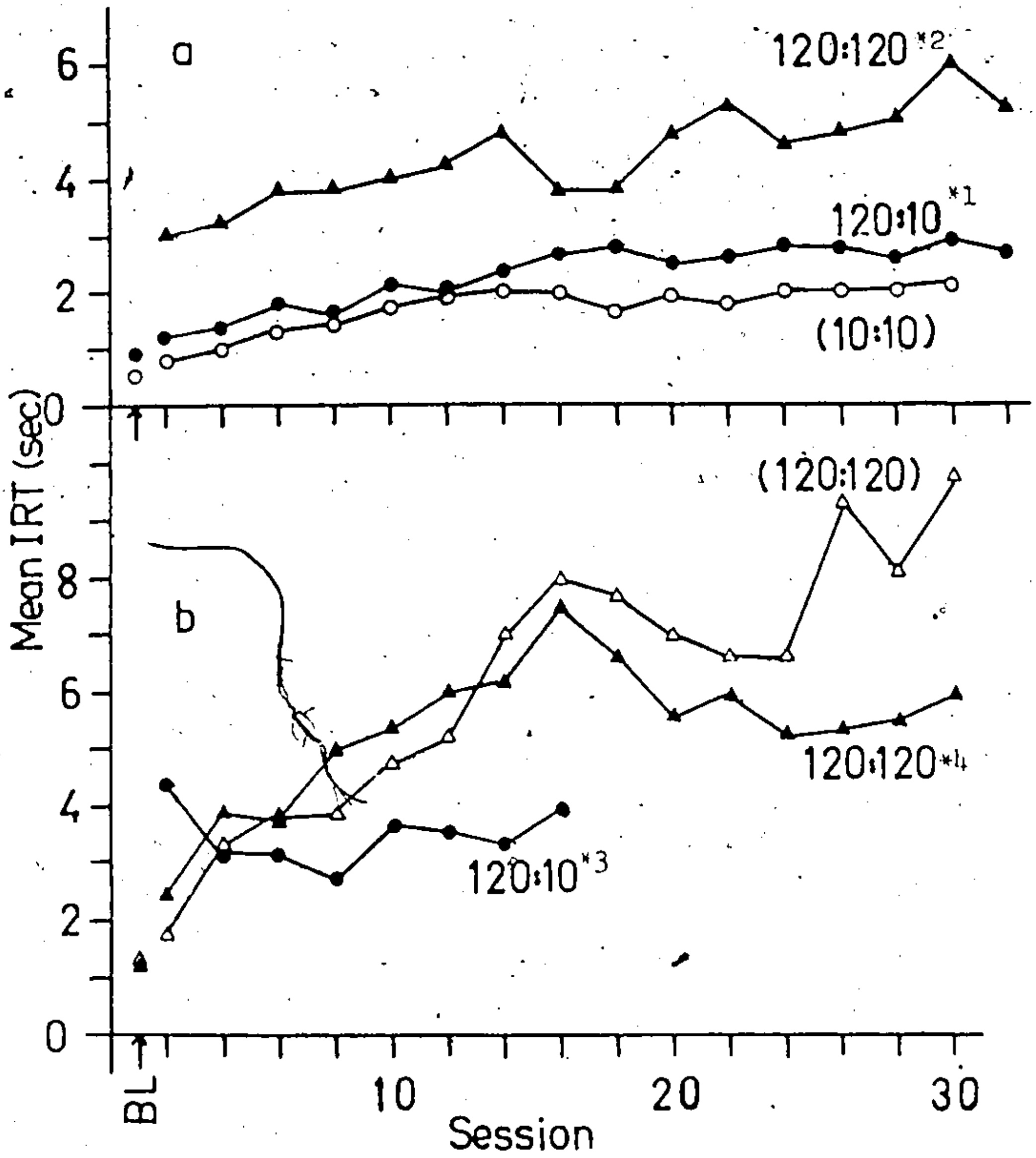

Figure 4-1. Group mean IRTs across sessions of Experiment 3. Data are plotted in two-session blocks. The same data for the 10:10 and 120:120 conditions of Experiment 1 are plotted in open symbols. Starred numbers indicate the order of treatments. BL indicates Baseline data.

followed by a slow diminution of the mean IRT while return to the Baseline condition reproduced the mean IRT observed on first exposure to this condition. The direct shift from the 120-second Baseline to 120:120 produced a rapid and large increase in the mean IRT to a level comparable to that attained in the first replication of this condition.

A comparison of the session IRT changes obtained in this experiment with those produced in Experiment 1 shows that the 10:10 condition of Experiment 1 is quite similar to the 120:10 condition of the present experiment. The 120:120 conditions (Figure 4-1b) are also highly similar until the 26th session, when the Experiment 1 group increased markedly while the present group maintained a stable mean IRT at a lower level.

The end-of-phase mean IRTs are presented in Figure 4-2, along with those produced by these subjects at 10 seconds in Experiment 1. Although there was a slight increase in the mean baseline IRT from 10 to 120 seconds, this difference falls just short of statistical significance with the small sample size involved; $t = 3.06$, $p = 0.055$. The difference in mean IRT at the 10-second and 120-second RIs with a 10-second Selectivity is not significant; $t = 1.23$, $p > 0.05$. However, the effect of increasing the Selectivity from 10 seconds to 120 seconds was significant, both in the differences between the 10:10 and 120:120 conditions; $t = 3.95$, $p < 0.05$; and between the 120:10 and 120:120 conditions; $t = 4.21$, $p < 0.05$.

The IRT distributions from the first three phases of Experiment

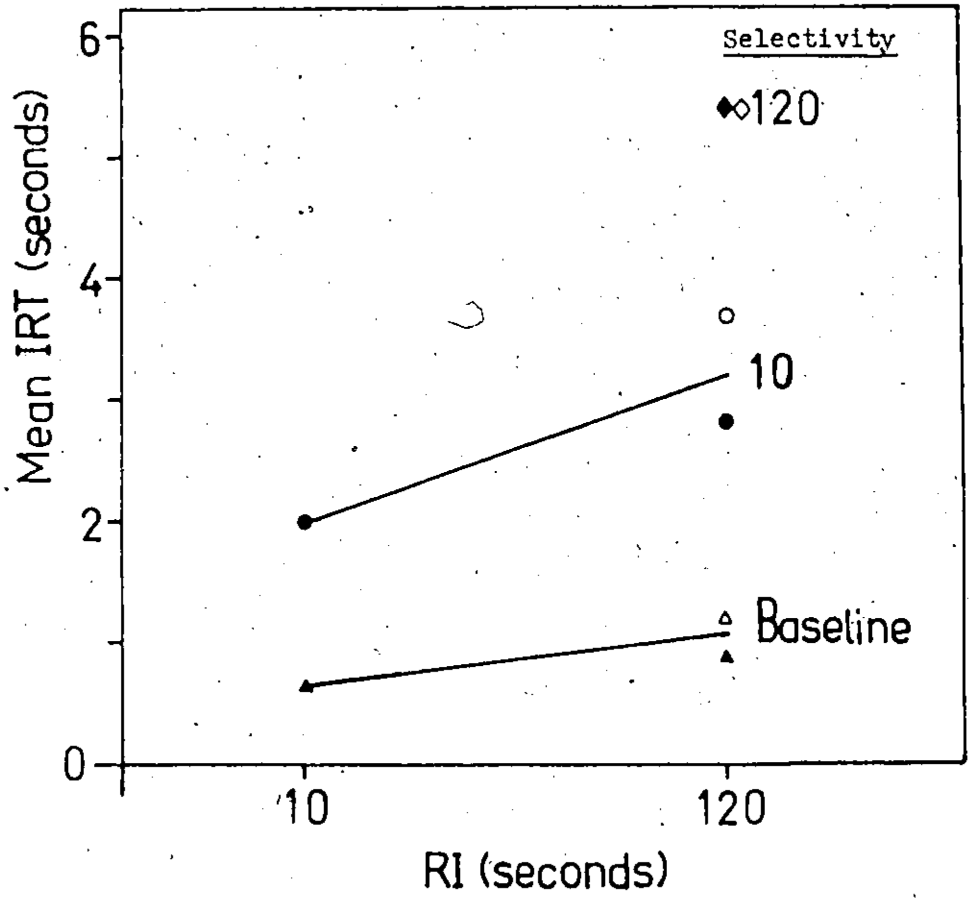

Figure 4-2. End-of-phase group mean IRTs from Experiment 3. Filled symbols are first replications and open symbols are second replications.

3 are presented in Figure 4-3. The baseline distributions were generally unimodal with a peak around 1.0 seconds while the Differential Phase distributions are clearly bimodal with a secondary mode at larger IRT values. This second peak of the distribution increased in displacement along the abscissa and in dispersion as the Selectivity increased from 10 seconds to 120 seconds. By comparing these distributions with those presented in Figure 2-3 for the same subjects at a 10-second RI, the effects of RI and Selectivity on the IRT distribution become obvious. The baseline distributions differ primarily in showing a longer tail at the higher RI value, a simple effect of RI. The 10:10 distributions of Experiment 1 and the 120:10 distributions of Experiment 3 are highly similar, substantiating the lack of RI effect noted in the mean IRTs obtained under these conditions. The large effects of Selectivity on mean IRT are reflected in the differences in the upper peaks of the IRT distributions while the small effects of RI are difficult to detect in either case.

Table 4-1 presents the end-of-phase data for this experiment and the comparable data from Experiment 1 for these subjects. The mean reinforced IRT and mean IRT were approximately equal during Baseline and the disparity between them increased from 1.80 seconds to 8.87 seconds when the Selectivity increased from 10 seconds to 120 seconds at the 120-second RI. The post-reinforcement pause also increased concomitantly with the increases in Selectivity and mean IRT.

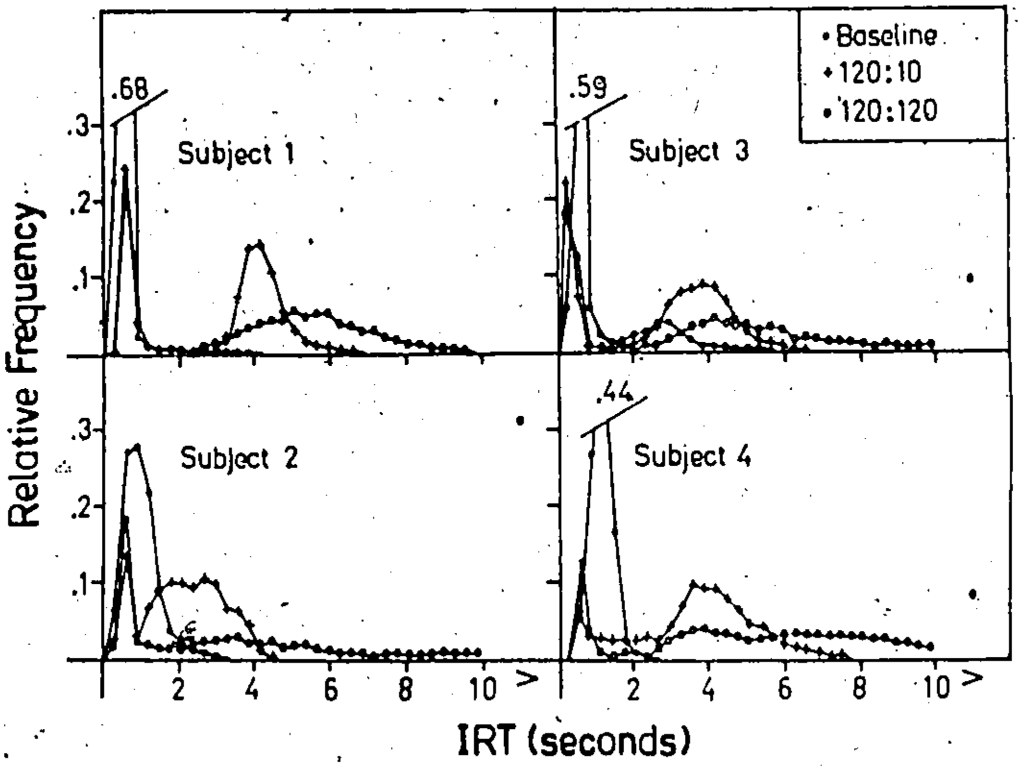

Figure 4-3. Relative frequency distributions of IRTs from the first three phases of Experiment 3.

Condition	Sessions	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion
Experiment 1					
Baseline 1	22	0.7	0.8	10	0.072
10:10	30	2.0	3.8	11	0.186
Experiment 3					
Baseline 1	13	0.9	1.0	123	0.007
120:10 (1)	32	2.8	4.6	124	0.023
120:120 (1)	32	5.2	14.1	116	0.045
120:10 (2)	16	3.7	5.6	119	0.031
Baseline 2	10	1.2	1.3	123	0.009
120:120 (2)	30	5.7	18.6	116	0.050

Table 4-1. End-of-phase data for Experiment 3. The data for these subjects in Experiment 1 is included for comparison. Numbers in parantheses indicated first and second occurrences of the schedule. The notation "10:10" indicates the RI and Selectivity values of the percentile reinforcement schedules during long IRT reinforcement.

Discussion

By separating the effects of Selectivity and RI in this experiment, the overshadowing influence of IRT reinforcement in the determination of response rate was clearly revealed. Whether a Selectivity criterion of 10 seconds was applied at a 10-second RI or at a 120-second RI the effect on mean IRT was the same, and much larger than the effect of this RI difference on mean baseline IRTs.

At the 120-second RI the 10-second Selectivity criterion was applied to IRTs in an inconsistent manner, in the sense that only one-twelfth of the criterial IRTs were actually reinforced. The difference between the mean reinforced IRT and the mean IRT was approximately the same under both the 10-second and 120-second RIs, so the extremity of the differential reinforcement may be said to be similar in the two cases. The similarity in results at the two RIs suggests that the important variable is not the consistency with which long IRTs are reinforced, but the difference between the reinforced IRTs and other IRTs in the IRT distribution. The effect of partial reinforcement of extreme IRTs was not significant.

The IRT distributions produced by the four subjects in this experiment and in Experiment 1 provide a clear picture of the manner in which Selectivity affects IRTs. Increasing selectivity caused movement and dispersion of the upper peak of the bimodal IRT distributions, while changes in RI had no discernible effect on the upper peak.

Chapter 5

Experiment 4

Interaction of Reinforcement Rate and IRT Reinforcement

Rationale

The results of Experiment 3 suggested that a 10-second Selectivity may produce longer IRTs at larger RIs. This would correspond to the marginal utility hypothesis of reinforcement effects proposed by Brandon (1969). In experiments concerned with the differentiation of number of responses, Brandon hypothesized that a reinforcement produces a greater effect on responding when it occurs in a context of low reinforcement rate. In Brandon's experiments, differential reinforcement of the number of responses was more effective in producing accurate responding at low temporal densities of reinforcement than at higher densities. He concluded that the role of his procedure of spacing out responding by preventing responding for extended periods was

> to increase the value of marginal reinforcements... by decreasing reinforcement density. This is analagous to the subjective utility function of decision theory, where the effectiveness of a reinforcer ... is an inverse function of the amount of reinforcer gained or held.

Extended to the present case, the marginal utility hypothesis predicts a greater effect of reinforcement on IRTs at longer RIs.

Even though the extremity of differential reinforcement is equated at the beginning of a Differential Phase, a 10-second Selectivity should produce longer IRTs at a 120-second RI than at a 10-second RI because the reinforcements at the 120-second RI occur in the context of a lower density of reinforcement. The altered effectiveness of selectivity at different RI values constitutes a prediction of the interaction of these two variables.

Although Experiment 3 failed to support this prediction, the data suggested a trend in the appropriate direction of divergence of the Differential and Baseline functions with increasing RI. The issue of interaction of IRT differentiation and RI is of some importance since it is intertwined with the question of the contribution of each variable to the control of response rate. The large difference in mean IRT observed in Experiment 1 between the 10:10 and 120:120 conditions was due to IRT differentiation, increased RI, and their interaction. The question of the relative importance of these three sources to the determination of the mean IRT [illegible]tivated the design of Experiment 4.

Experiment 4 exposed pigeons to three levels of Selectivity (including the nonselective Baseline), and two levels of RI in six combinations of these two variables. The RI differed for different subjects and selectivity varied both between groups in each phase and within groups across the four phases of the experiment. The experiment may be viewed as two replications of the basic experiment in which each of four groups of subjects received a different combination of RI and nonzero selectivity. The second replication reversed the Selectivity values used in the first replication.

Procedure

Sixteen experimentally naive pigeons were exposed to six differentiation conditions in four phases. Four pigeons composed each of four groups receiving different combinations of selectivity and RI. Two values of RI -- 30 seconds and 120 seconds -- and two values of Selectivity -- 10 seconds and 30 seconds -- were combined to produce the four conditions: 30:10, 30:30, 120:10, and 120:30. In this notation the first number indicates the RI and the second number the Selectivity of the percentile schedule. Two replications, each involving a Baseline Phase followed by a Differential Phase were run with 16-session Baseline Phases and 30-session Differential Phases. Table 5-1 presents the sequence of treatments for each of the four groups of pigeons.

Results

The group mean IRT curves obtained during the first Differential Phase are presented in Figure 5-1. The groups overlapped considerably until session 14, when the 120:30 group increased markedly. The other three groups remained indistinguishable until session 24 when the 30:30 group diverged in an upward direction. The mean IRTs from the last three sessions of the first Baseline Phase and the

Subject Number	First Baseline Phase	First Differential Phase	Second Baseline Phase	Second Differential Phase
17 - 20	-	30:10	-	30:30
21 - 24	-	30:30	-	30:10
25 - 28	-	120:10	-	120:30
29 - 32	-	120:30	-	120:10

Table 5-1. Sequence of treatments for the subjects of Experiment 4. The notation "30:10" indicates the RI and Selectivity values of the percentile reinforcement schedule during long IRT reinforcement.

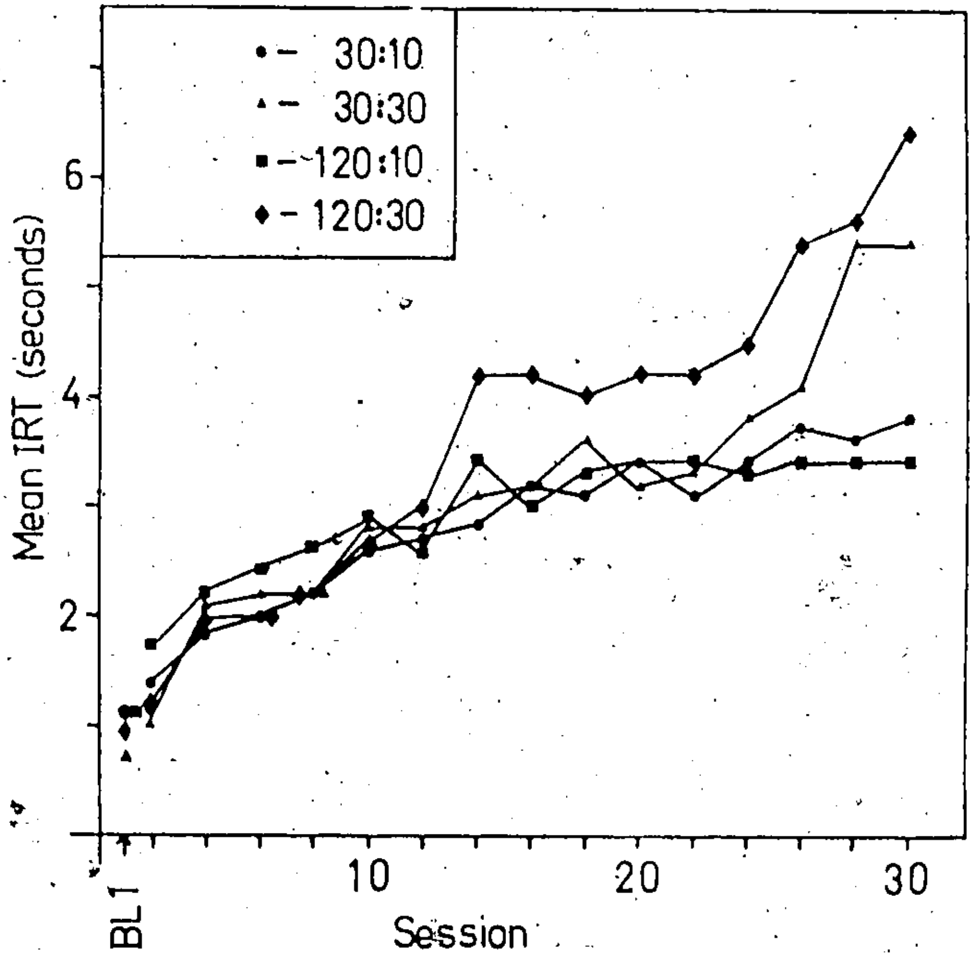

Figure 5-1. Group mean IRTs across sessions for the first Differential Phase of Experiment 4. Data are plotted in two-session blocks. Percentile parameters are indicated in the upper left corner of the figure, for the four groups of subjects.

last six sessions of the first Differential Phase are presented as filled symbols and dashed lines in Figure 5-2. The different Selectivity values produced large differences in the mean IRT; F (1,12) = 5.48, $p < 0.05$. The effect of RI during the Differential Phase was not significant; F (1,12) < 1.0. The interaction of Selectivity and RI was also nonsignificant; F (1,12) < 1.0. Similarly, RI had no effect on the mean IRTs obtained during the Baseline Phase; F (1,14) < 1.0

Figure 5-3 presents the session-by-session IRT changes for the four groups during the second Differential Phase. The groups were more clearly discriminable throughout the phase than they were during the first replication. The three highest groups increased at about the same rate until the tenth session, when the 120:10 group levelled off. The lowest group, 30:10, increased more slowly and stopped sooner while the 30-second Selectivity groups continued increasing almost throughout the phase. The highest group in this replication, at 120:30, was the group with the lowest mean IRT during the first replication at 120:10.

The end-of-phase data for the second replication are presented in Figure 5-2 with open symbols and solid lines. The effect of selectivity was quite large during differential conditions; F (1,12) = 23.90, $p < 0.001$, while the effect of RI; F (1,12) = 3.49, $p < 0.1$, and the interaction; F (1,12) < 1.0, were not significant. However, the effect of RI on the mean IRTs produced during the second Baseline Phase was significant; F (1,14) = 5.13, $p < 0.05$.

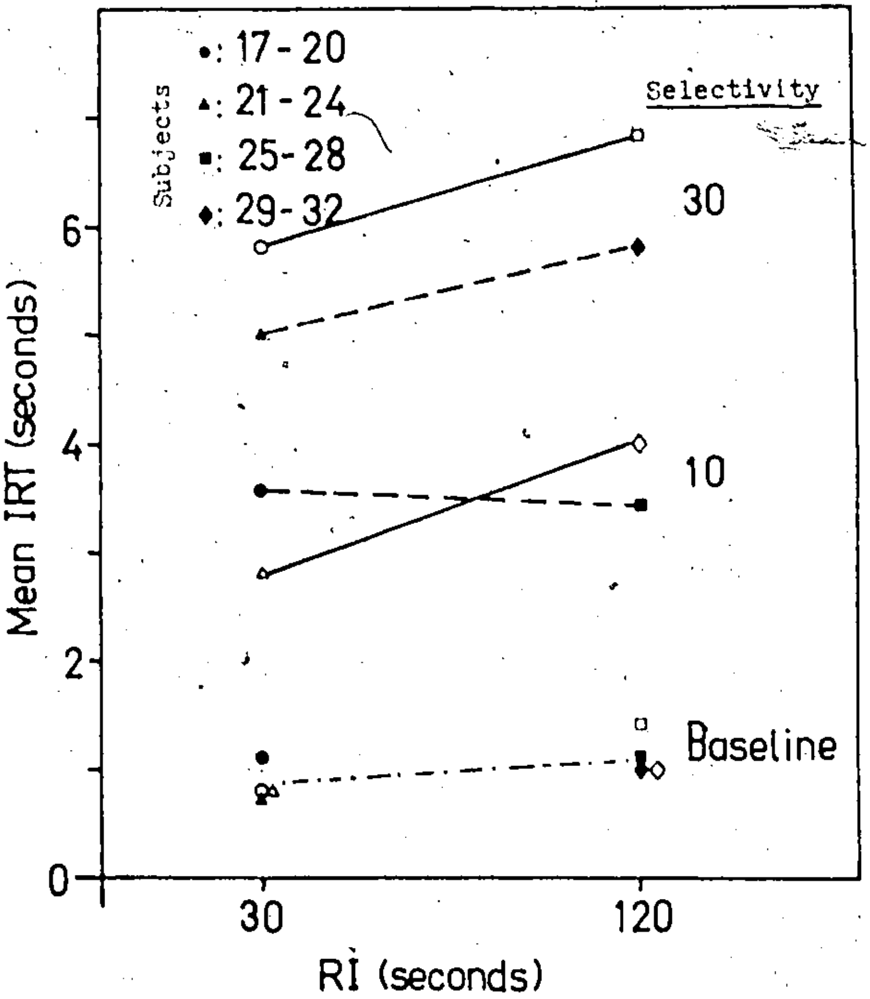

Figure 5-2. End-of-phase group mean IRTs from the four phases of Experiment 4. First Differential Phase data are plotted in filled symbols and dotted lines. Second Differential Phase data are plotted in open symbols and solid lines. Symbol shapes are coded by subject group as indicated in the upper left corner of the figure.

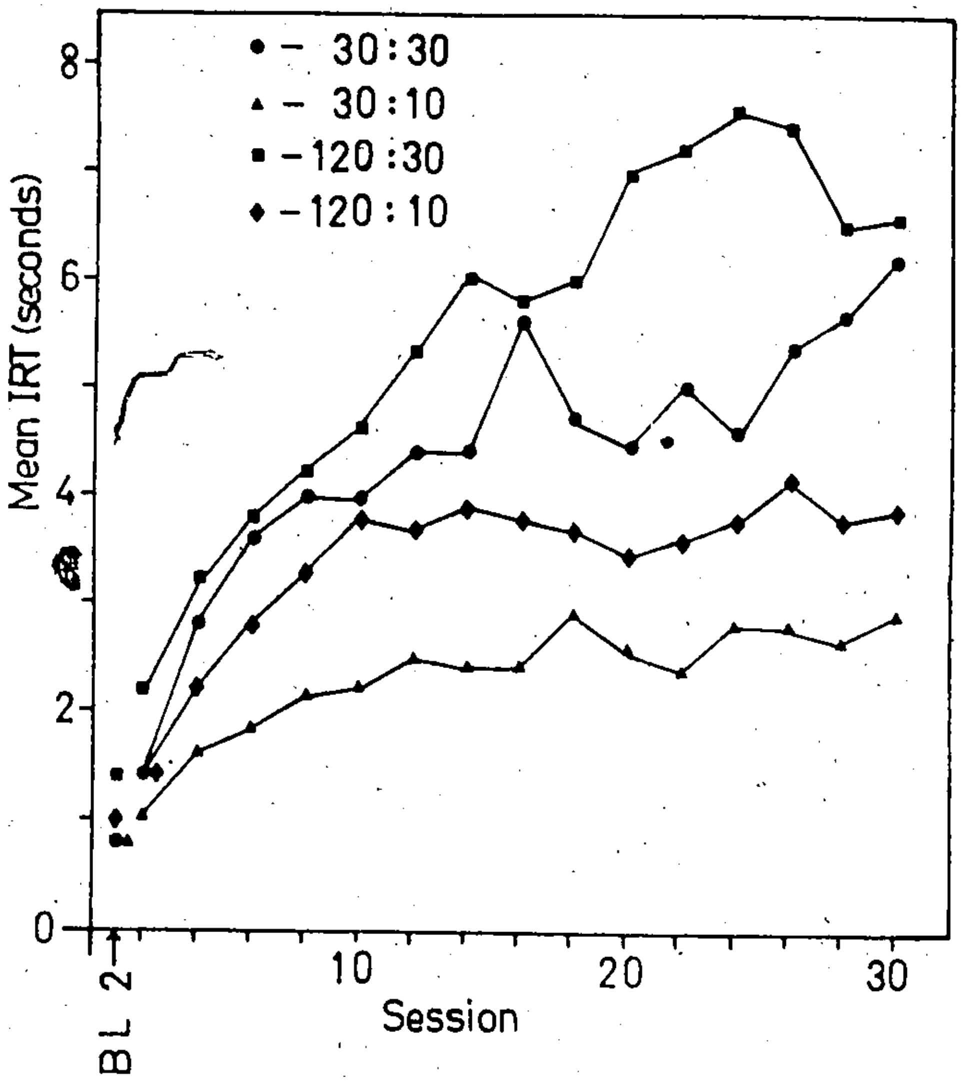

Figure 5-3. Group mean IRTs across sessions for the second Differential Phase of Experiment 4. Data are plotted in two-session blocks. Percentile parameters are indicated in the upper left corner of the figure for the four groups of subjects.

Relative frequency distributions of IRTs are presented in Figure 5-4 for the first Baseline and second Differential Phases. The effect of selectivity on the upper peak of the distributions is quite clear in this figure. The 30-second Selectivity produced upper peaks at higher values and with greater dispersion than the 10-second Selectivity, with no apparent effect of RI on this peak. Effects of the variables on the lower peak of the distribution were not consistent between groups and no general effects are discernible.

The group mean IRT, reinforced IRT, obtained RI, and reinforcement probability are presented in Table 5-2 for the ends of the four phases of the experiment. Program control of RI was good in all cases except the first Baseline Phase, where an error in the control program produced shorter RIs in all conditions. This error had no systematic effects on Baseline IRTs and was corrected in the succeeding phases. The ratio between the reinforced IRT and the mean IRT increased from 1.08 during Baseline Phases, through 1.50 during 10-second Selectivity Differential Phases, to 1.87 during 30-second Selectivity Differential Phases. The probability of reinforcement was higher during Differential Phases (when IRTs were longer) than during Baseline Phases, averaging 0.087 and 0.027 reinforcements per response respectively.

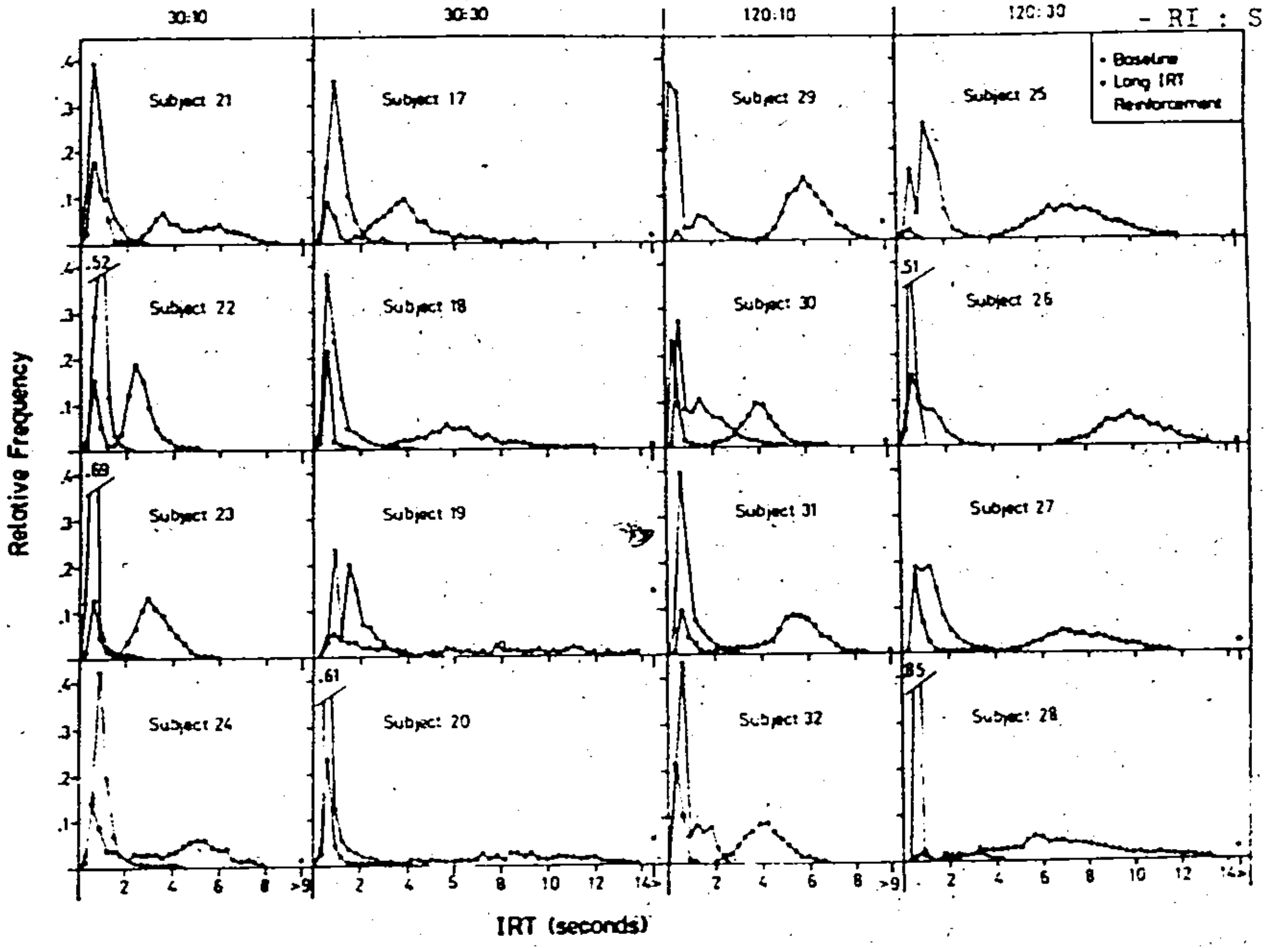

Figure 5-4. Relative frequency distributions of IRTs from the first Baseline and second Differential Phase of Experiment 4.

Subjects	Condition	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion
17 - 20	Baseline 1	1.1	1.0	24	0.044
	Baseline 2	0.8	1.0	30	0.032
	30:10	3.7	5.4	29	0.131
	30:30	5.6	12.3	35	0.162
21 - 24	Baseline 1	0.7	0.8	23	0.034
	Baseline 2	0.8	0.8	31	0.027
	30:10	2.8	4.7	30	0.091
	30:30	4.9	9.9	33	0.150
25 - 28	Baseline 1	1.1	1.1	119	0.009
	Baseline 2	1.4	1.6	129	0.012
	120:10	3.4	4.8	124	0.028
	120:30	6.7	10.6	116	0.059
29 - 32	Baseline 1	1.0	1.1	85	0.013
	Baseline 2	1.0	1.1	127	0.009
	120:10	4.0	5.8	127	0.031
	120:30	5.8	9.3	127	0.046

Table 5-2. End-of-phase data for the four phases of Experiment 4. All time data are in seconds. Sequence of treatments is presented in Table 5-1. The notation "30:10" indicates the RI and Selectivity values of the percentile reinforcement schedule during long IRT reinforcement.

Discussion

Differential reinforcement of long IRTs was the principal determiner of response rate in this experiment. A fourfold increase in RI from 30 to 120 seconds produced a 50% increase in IRT when IRTs were not differentially reinforced (data of second Baseline), from 0.8 to 1.2 seconds. This contribution from reinforcement rate was overshadowed by the large effects of IRT reinforcement produced during differential conditions. A Selectivity of 10 seconds produced nearly a quadrupling of the baseline IRT, a change from 0.9 seconds to 3.4 seconds (data of second Differential Phase). A 30-second Selectivity produced an even larger change over the baseline IRT, from 1.1 to 6.3 seconds (second Differential Phase, summing over RIs). These 2 to 5 second changes in IRT would tend to obscure a 0.4 second change caused by RI differences and indeed no effects of RI were detected during the Differential Phases.

This experiment supports the claim that the major part of the long IRT differentiation function obtained in Experiment 1 (Figure 2-2) was due to the effects of IRT reinforcement, and only a minor part is ascribable to differences in RI or to the interaction of these variables. The absence of any interaction of RI and IRT reinforcement indicates the inapplicability of a marginal utility hypothesis to the present results. Reinforcement produced similar effects on IRTs in situations which differed in reinforcement density by a factor of four.

The baseline IRT differences are quite comparable in this experiment and Experiment 1, indicating the replicability of the small but persistent RI effect. In Experiment 1, RIs of 30 and 120 seconds produced baseline IRTs of 0.8 and 1.3 seconds. In Experiment 4, second Baseline Phase, the comparable figures were 0.8 and 1.2 seconds. The other condition of Experiment 4 which replicated an Experiment 1 condition also produced similar results. The 30:30 condition in Experiment 4 produced a 5.0 second mean IRT during the first Differential Phase and a 5.8 second mean IRT during the second Differential Phase, both respectably close to the 5.0 second mean IRT obtained with this condition in Experiment 1.

The IRT distributions in this experiment, as in Experiment 1, revealed the manner in which selectivity manipulations modify the mean IRT. The upper peak of the distributions changed in response to changes in selectivity and were unaffected by changes in RI. This result suggests a duality in the effects of reinforcement on response rate. This suggestion is pursued in the concluding section.

Chapter 6

Conclusions

This series of experiments has demonstrated the efficacy of IRT reinforcement in the modulation of response rate independent of changes in the temporal density of reinforcement. It has also shown that reinforcement rate can affect response rate even in the absence of direct differential reinforcement of IRTs. The final major finding of this study is the dominance of IRT reinforcement in the determination of response rate, almost to the exclusion of reinforcement rate effects, under the conditions of the paradigm used here.

The results lend themselves to interpretation in terms of a dual effect of reinforcement on responding, in a manner proposed by Norman's (1966) mathematical model of responding produced by IRT > t reinforcement schedules. According to Norman's hypothesis, reinforcement has both a "strengthening" and a "differentiating" effect on responding. The "strengthening" effect on a response increases the probability of occurrence of the response, without reference to its associated IRT. In terms of the model, this strengthening effect increases the relative frequency of IRTs drawn from a distribution of IRTs the length of which approximate the minimum possible. The "differentiating" effect of reinforcement conditioned control of the pigeon's disk-pecking response. According to this interpretation some disk pecks are controlled by the disk light - reinforcement pairings in the manner of classically-conditioned responses and some are controlled by the response-reinforcement contingencies in the manner of instrumentally-conditioned responses. The maintenance of a low peak in the IRT distribution under conditions of long IRT reinforcement would then be ascribable to the classically-conditioned pecks, while the IRTs of the instrumentally-conditioned pecks would change with the response-reinforcement contingencies. Whether short IRT pecks in the present experiments did indeed behave as classically-conditioned responses with respect to the disk light - reinforcement pairings is not determinable with the available data.

The relationships between response rate and reinforcement observed in the present study strongly recommend the IRT as a useful level of analysis for the effects of reinforcement on responding. Contingencies between IRT values and reinforcement presentation determined in large part the recurrence of IRT values. Changes in overall response rates were reflective of more particular changes in the distribution of IRTs, and analysis of the IRT distributions allowed a clearer interpretation of the data than simple changes in overall response rate. All of this argues for the advisability of analysing response rate changes in terms of shifts in the IRT distributions underlying these changes.

The utility of speaking in terms of the interval between events rather than the rate of occurrence of events is also suggested by experiments conducted within the framework of the relative law of effect. As mentioned in the Introduction to this thesis, the relative law of effect encompasses a wider range of phenomena than is dealt with here. However, it is interesting to note that within the context of interval-based reinforcement schedules, the hyperbolic relation between rates of responding and reinforcement described by Equation 1 is a linear relation between interresponse time and reinforcement interval. A transformation of Equation 1 yields the following relationship:

$$\frac{1}{P} = \frac{1}{k} + \frac{R_o}{k} \times \frac{1}{R}$$

or,

7

$$IRT = c + b \times RI$$

where b and c are constants. Although recognized by investigators of interval schedule phenomena, this linear relationship was seen as a convenient curve-fitting procedure (Cohen, 1973) rather than as suggestive of theoretical ramifications. The present data suggest that the observed hyperbolic relation between rates may be heavily influenced by IRT reinforcement effects. This raises the question of the generality of the results reported here, in particular their applicability to the variable interval schedule data modelled by Equation 1.

The results presented here in combination with data obtained on synthetic variable interval schedules (Anger, 1956) provide a basis for the argument that IRT reinforcement affects response rate on standard variable interval schedules. As demonstrated here, small changes in IRT selectivity can produce large changes in mean IRT, while large changes in the reinforcement interval produce only small changes in mean IRT when there is no differential reinforcement of IRTs. The applicability of the selectivity results to variable interval schedules is limited by the procedural differences between IRT reinforcement on variable interval and percentile reinforcement schedules. In the case of percentile schedules, the reinforcement criterion sets a sharp delineation between reinforced and nonreinforced IRT classes, the reinforcement probability being some fixed value in the first instance and zero in the second. Although the criterion shifts as the behavior changes, the sharpness of the delineation remains. The situation on variable interval schedules is quite different, since the reinforcement probability changes continuously with the IRT length. The global term selectivity" obscures this procedural difference in the mode of IRT reinforcement, which may or may not be crucial. At the present time it is sufficient to note that the small effect of RI on mean IRT in the present studies suggests that the changes of the generality of the results reported here, in particular their applicability to the variable interval schedule data modelled by Equation 1.

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Many animals are sensitive to the passage of time, showing temporally cyclic patterns in behavior and sometimes the ability to discriminate between short temporal intervals. Such observations establish the possibility of time forming the basis for response rate determination, but the status of the IRT as a property of behavior is somewhat peculiar. Between any two responses of interest to the experimenter, the organism is doing something, even if that something is merely standing still. If reinforcement increases the probability of an IRT, what happens to the behavior occurring between the recorded behaviors and within the IRT? This is a question which has bothered several investigators and has generated a body of research on the collateral or mediating behavior occurring within the IRT interval (e.g., Laties, Weiss, & Weiss, 1969).

Reynolds and McLeod (1970) have suggested that mediating behavior provides the appropriate level of analysis of relationships between IRTs and reinforcement (pp. 98-99):

> Those behaviors and chains of behaviors that occur in the reinforced sequences will be strengthened and the IRTs that tend to occur when those behaviors are being emitted will increase in frequency. This alternative to IRT-reinforcement really suggests that an IRT is not a reinforceable feature of behavior at all but rather only appears to be because it is necessarily associated with features of behavior that are controlled by reinforcement.

Analyses in terms of IRTs and mediating behaviors are not incompatible. The question of which provides the better level of analysis can be answered only by experiments generating comparable relations between behavioral measures and reinforcement. The present study demonstrates the usefulness of the IRT as a measure of behavior in its relation with reinforcement. No comparable data for mediating behaviors exist and until they do Reynolds and McLeod's argument is wholly speculative.

Unconfounding the strengthening and differentiating effects of reinforcement on responding with percentile reinforcement schedules has established the discriminability of these effects. Although IRT differentiation as it occurs on percentile schedules could be said to be outside the purview of the relative law of effect and the data base it is concerned with, a synthesis of this law and IRT reinforcement theory may be a profitable venture. One possibility is suggested by definition of the response unit affected by reinforcement. This resolution of the two hypotheses would involve the strengthening of IRTs rather than responses per se. Shimp (1972) has proposed such a formulation in his suggestion that IRTs are controlled by their relative rates of reinforcement. Norman's (1966) formulation described earlier indicates a stronger basis for synthesis since it maintains a distinction between strengthening and differentiating effects of reinforcement, a distinction whose validity is underlined by the present thesis.

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APPENDIX A

End-of-phase data of the individual subjects of Experiment 1

Table A-1 : First Baseline

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion	Post-Reinforcement Pause
1	0.49	0.60	11	0.046	1.06
2	0.85	0.87	10	0.086	2.00
3	0.81	0.90	11	0.076	1.73
4	0.65	0.66	8	0.079	2.03
Mean	0.70	0.76	10	0.072	1.72
5	0.54	0.53	34	0.016	2.45
6	0.88	0.84	32	0.028	3.26
7	1.14	1.15	32	0.036	2.35
8	0.75	0.72	29	0.025	2.34
Mean	0.82	0.81	32	0.026	2.60
9	1.04	0.93	54	0.019	3.67
10	1.22	1.17	52	0.023	2.13
11	0.86	0.83	62	0.014	3.13
12	0.90	0.85	62	0.014	2.27
Mean	1.01	0.95	58	0.018	2.80
13	1.56	1.81	124	0.013	35.83
14	0.99	0.92	113	0.009	16.83
15	0.95	1.10	126	0.008	10.99
16	1.85	1.72	110	0.017	7.87
Mean	1.34	1.39	118	0.011	17.88

Table A-2 : Second Baseline

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion	Post-Reinforcement Pause
1	0.43	0.46	11	0.040	1.09
2	0.61	0.52	10	0.059	1.50
3	0.72	0.71	10	0.074	1.44
4	0.69	0.68	10	0.072	2.55
Mean	0.61	0.59	10	0.062	1.65
5	0.45	0.42	30	0.015	1.75
6	0.70	0.64	30	0.024	2.87
7	1.31	1.30	26	0.050	3.22
8	0.88	0.76	28	0.032	1.60
Mean	0.84	0.78	28	0.030	2.36
9	0.99	0.91	61	0.016	2.41
10	0.79	0.68	54	0.015	1.61
11	0.69	0.71	67	0.010	5.55
12	0.83	0.91	62	0.013	8.90
Mean	0.82	0.80	61	0.014	4.62
13	1.16	1.00	91	0.013	26.02
14	1.38	1.39	120	0.012	16.29
15	1.50	1.55	123	0.012	9.59
16	1.43	1.39	111	0.013	11.91
Mean	1.37	1.33	111	0.012	15.95

Table A-3 : Third Baseline

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion	Post-Reinforcement Pause
1	0.43	0.38	9	0.046	1.00
2	0.63	0.63	9	0.072	2.26
3	0.59	0.60	9	0.067	2.15
4	0.59	0.64	10	0.61	4.67
Mean	0.56	0.56	9	0.061	2.52
5	0.46	0.49	27	0.017	2.92
6	0.78	0.81	28	0.028	2.96
7	1.19	1.34	35	0.034	4.87
8	0.81	0.80	29	0.028	1.78
Mean	0.81	0.86	30	0.027	3.13
9	1.14	1.16	59	0.019	2.67
10	1.11	1.28	61	0.018	1.12
11	0.64	0.69	61	0.010	2.05
12	0.75	0.75	61	0.012	4.36
Mean	0.91	0.97	61	0.015	2.55
13	1.27	1.04	83	0.015	15.25
14	0.94	0.83	136	0.007	15.91
15	0.99	1.10	145	0.007	22.60
16	1.07	1.07	91	0.012	14.30
Mean	1.07	1.01	114	0.010	17.02

Table A-4 : Long IRT Reinforcement

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion	Post-Reinforcement Pause
1	2.88	5.32	10	0.280	5.14
2	2.07	4.05	11	0.183	4.59
3	2.12	3.73	11	0.192	4.60
4	1.00	1.97	10	0.097	4.09
Mean	4.60	3.77	11	0.188	4.60
5	4.75	6.59	28	0.170	6.40
6	4.67	9.05	31	0.151	8.86
7	6.01	9.95	33	0.182	10.34
8	4.58	7.18	34	0.134	5.69
Mean	5.00	8.19	32	0.159	7.83
9	3.30	9.15	61	0.054	3.57
10	4.03	10.45	62	0.065	6.65
11	6.22	15.69	66	0.094	13.36
12	3.72	12.11	66	0.056	8.73
Mean	4.31	11.85	64	0.067	9.33
13	5.33	12.92	121	0.044	8.17
14	12.81	32.99	139	0.092	28.53
15	9.23	18.95	124	0.074	16.05
16	7.16	23.45	134	0.053	22.26
Mean	8.63	22.07	130	0.66	18.75

Table A-5 : Short IRT Reinforcement

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion	Post-Reinforcement Pause
1	0.35	0.14	11	0.032	1.16
2	0.54	0.18	10	0.056	1.30
3	0.49	0.13	9	0.055	1.99
4	0.94	0.18	10	0.090	2.60
Mean	0.58	0.18	10	0.058	1.76
5	0.53	0.21	32	0.017	1.08
6	0.48	0.11	29	0.017	2.70
7	1.07	0.24	27	0.040	3.47
8	0.77	0.10	30	0.026	1.33
Mean	0.71	0.16	29	0.025	2.14
9	0.93	0.19	51	0.018	3.01
10	0.71	0.19	67	0.011	1.52
11	0.5[illegible]	0.14	61	0.009	1.39
12	0.75	0.10	57	0.013	1.80
Mean	0.73	0.15	59	0.013	1.93
13	1.28	0.21	121	0.011	52.38
14	1.12	0.22	110	0.010	13.62
15	0.74	0.10	130	0.006	27.33
16	1.00	0.10	122	0.008	9.67
Mean	1.04	0.16	122	0.009	25.75

APPENDIX B

End-of-phase data of the individual subjects of Experiment 2

Table B-1 : First Baseline

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion
13	1.4	1.2	372	0.004
14	1.2	1.2	340	0.004
15	1.0	0.9	340	0.003
16	1.4	1.6	396	0.003
Mean	1.2	1.2	362	0.003

Table B-2 : Second Baseline

13	1.4	1.5	444	0.003
14	1.1	0.9	359	0.003
15	1.1	1.4	330	0.003
16	2.0	2.0	328	0.006
Mean	1.4	1.4	365	0.004

Table B-3 : Long IRT Reinforcement

13	8.1	30.8	289	0.028
14	9.2	21.4	285	0.032
15	10.2	29.3	280	0.036
16	4.2	29.0	279	0.015
Mean	7.9	27.6	283	0.028

APPENDIX C

End-of-phase data of the individual subjects of Experiment 3

Table C-1 : First Baseline

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion
1	0.5	0.8	150	0.003
2	0.9	0.9	105	0.008
3	1.1	1.2	112	0.010
4	1.0	1.0	126	0.008
Mean	0.9	1.0	123	0.007

Table C-2 : Second Baseline

1	1.0	1.4	119	0.008
2	0.9	0.8	109	0.013
3	1.7	1.7	137	0.013
4	1.1	1.2	128	0.008
Mean	1.2	1.3	123	0.009

Table C-3 : First 120:10

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion
1	3.2	5.4	127	0.025
2	1.9	3.3	120	0.016
3	2.7	4.7	125	0.022
4	3.6	5.1	122	0.030
Mean	2.8	4.6	124	0.022

Table C-4 : Second 120:10

1	4.4	6.7	130	0.034
2	4.0	5.3	114	0.036
3	2.1	5.6	113	0.027
4	3.2	4.7	118	0.028
Mean	3.7	5.6	119	0.031

Table C-5 : First 120:120

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion
1	4.3	11.2	123	0.035
2	7.0	20.7	117	0.060
3	4.3	12.2	113	0.038
4	5.4	12.4	111	0.049
Mean	5.3	14.1	116	0.046

Table C-6 : Second 120:120

1	4.1	19.4	121	0.034
2	5.8	17.1	103	0.056
3	6.2	15.0	116	0.055
4	6.7	23.0	123	0.054
Mean	5.7	18.6	116	0.050

APPENDIX D

End-of-phase data of the individual subjects of Experiment 4.

Table D-1 : First Baseline

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion
17	0.9	0.8	16	0.056
18	0.9	0.8	29	0.031
19	1.7	2.0	27	0.063
20	0.8	0.6	24	0.033
Mean	1.1	1.0	24	0.044
21	0.7	0.7	17	0.041
22	0.7	0.6	22	0.032
23	0.5	0.6	16	0.031
24	1.0	1.2	34	0.029
Mean	0.7	0.8	23	0.034
25	1.4	1.5	141	0.010
26	1.1	1.0	120	0.009
27	1.3	1.2	126	0.010
28	0.7	0.6	88	0.008
Mean	1.1	1.1	119	0.009
29	0.9	0.8	70	0.013
30	1.5	1.7	92	0.016
31	0.8	0.8	108	0.007
32	0.8	1.0	70	0.011
Mean	1.0	1.1	85	0.013

Table D-2 : Second Baseline

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion
17	0.8	1.1	29	0.028
18	1.0	1.1	28	0.036
19	0.9	0.8	27	0.033
20	0.7	0.8	34	0.020
Mean	0.8	1.0	30	0.032
21	0.9	1.0	27	0.033
22	0.7	0.8	34	0.020
23	0.7	0.7	30	0.023
24	0.9	0.9	35	0.026
Mean	0.8	0.8	31	0.027
25	2.2	2.4	142	0.015
26	1.0	1.3	126	0.012
27	1.4	1.3	121	0.012
28	1.1	1.3	126	0.009
Mean	1.4	1.6	129	0.012
29	0.8	0.8	112	0.007
30	1.3	1.4	120	0.011
31	0.9	1.1	142	0.006
32	0.9	1.1	136	0.007
Mean	1.0	1.1	127	0.009

Table D-3 : 10-second Selectivity

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion
17	3.7	4.9	27	0.136
18	3.0	4.8	32	0.092
19	5.6	7.3	29	0.193
20	2.6	4.4	26	0.103
Mean	3.7	5.4	29	0.131
21	3.2	5.6	30	0.106
22	2.0	3.4	29	0.071
23	2.6	4.0	31	0.084
24	3.3	5.7	32	0.104
Mean	2.8	4.7	30	0.091
25	4.4	5.4	112	0.040
26	2.7	4.5	127	0.022
27	1.9	3.4	122	0.016
28	4.6	5.8	135	0.034
Mean	3.4	4.8	124	0.028
29	6.2	6.8	129	0.048
30	2.7	5.2	127	0.021
31	4.3	6.2	138	0.031
32	2.8	5.0	114	0.024
Mean	4.0	5.8	127	0.031

Table D-4 : 30-second Selectivity

Subject Number	Mean IRT	Mean Reinforced IRT	Obtained RI	Reinforced Proportion
17	4.2	10.8	34	0.125
18	4.8	9.9	36	0.132
19	7.4	15.4	34	0.217
20	6.1	13.2	35	0.174
Mean	5.6	12.3	35	0.162
21	6.2	14.1	32	0.192
22	6.2	10.2	32	0.194
23	3.6	6.9	33	0.112
24	3.5	8.5	35	0.101
Mean	4.9	9.9	33	0.150
25	7.4	9.8	109	0.068
26	7.3	11.2	108	0.067
27	5.7	10.8	135	0.042
28	6.6	10.5	110	0.060
Mean	6.7	10.6	116	0.059
29	8.0	13.1	131	0.061
30	6.2	9.5	128	0.048
31	5.0	8.7	118	0.042
32	3.9	7.7	108	0.036
Mean	5.8	9.8	121	0.047