The Relative Susceptibilities of Interresponse Times and Post-Reinforcement Pauses to Differential Reinforcement

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THE RELATIVE SUSCEPTIBILITIES OF INTERRESPONSE TIMES
AND POST-REINFORCEMENT PAUSES TO DIFFERENTIAL
REINFORCEMENT

by

Nancy L. Trapp

A dissertation submitted in partial fulfillment
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Nancy Trapp
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The Relative Susceptibilities of Interresponse Times and Post-Reinforcement Pauses to Differential Reinforcement

by

Nancy L. Trapp, Doctor of Philosophy

Utah State University, 1987

Post-reinforcement pauses (PRPs) and interresponse times (IRTs) were examined to determine if these two temporal units changed in a similar fashion as a function of the delivery of differential reinforcement. Two experiments were conducted. In Experiment 1, four pigeons were exposed to a series of procedures in which PRP and IRT durations were gradually increased and then decreased. A fixed-ratio two (FR 2) differentiation schedule was used. Reinforcement was delivered if the PRP or IRT durations were greater than (PRP > and IRT > procedures) or less than (PRP < and IRT < procedures) specified temporal criteria. Criteria were gradually changed across procedures. Results showed that PRPs and IRTs changed in accordance with the differential reinforcement as specified by the various contingencies. When PRPs and IRTs were free to vary, the PRPs tended to change in a direction consistent with the IRT shaping contingency; whereas, the IRTs tended to shorten regardless
of the PRP shaping contingency. In Experiment 2, two subjects were exposed to both an FR 2 and FR 1 schedule to determine if schedule size influenced the effects obtained on the differentiation procedures. PRPs were systematically changed using a differentiation procedure with a response requirement of either FR 1 or FR 2. Results showed similar changes in PRP durations between FR 1 and FR 2 differentiation procedures. An analysis of errors made on each shaping condition in both experiments was conducted to determine whether PRPs or IRTs were more susceptible to the differential reinforcement contingencies. Fewer errors were made on the PRP shaping conditions, indicating that PRPs were more easily changed. Implications for a comprehensive theory of reinforcement were discussed.

(125 pages)
CHAPTER I

INTRODUCTION

Skinner (1938, 1953, 1957) has discussed the importance of rate of response as a measure of operant behavior. Traditionally, rate of response has been calculated by dividing the total number of responses in a session by the total time in a session, minus the time utilized by food delivery. Response rate can be sectioned into four distinctive temporal elements or units. The first temporal unit is the time from termination of a reinforcement cycle to the first response, and has been called the post-reinforcement pause (PRP). A second temporal unit is the time between each individual response, which is known as the interresponse time (IRT). The third temporal unit is the length of time of each individual response, and is referred to as response duration. And the fourth temporal unit is the length of time required to complete a sequence of behavior. This temporal unit is called the work time.

Skinner (1938) was the first to identify and discuss the important functions of temporal units in controlling and understanding patterns of behavior, focusing initially on interresponse times. He suggested that the different rates of responding generated by fixed-interval (FI) and fixed-ratio (FR) schedules of reinforcement might be due to the effects of differential reinforcement on IRTs within each of these schedules. Since Skinner's early research,
numerous studies have demonstrated the importance of both
differential reinforcement and temporal units to the
understanding of behavior (Morse, 1966; Zeiler, 1977, 1984).

Research on temporal relations has focused primarily on
the manipulation of these temporal units indirectly by
implementing a specific change in a variable other than the
temporal unit itself, such as number of required responses
or schedule of reinforcement, and then the observation of
the concurrent change in the temporal units (Felton & Lyon,
1966). In addition, research has focused on the temporal
units themselves as events which are directly manipulable.
This research has utilized reinforcement schedules that are
referred to as temporal differentiation procedures (Zeiler,
1981). For example, Catania (1970) gradually increased PRPs
by presenting a reinforcing stimulus immediately after a
single peck, if a prior PRP was longer than a specified
duration. Staddon (1965) increased IRT lengths by directly
reinforcing IRTs of a specified duration. Platt, Kuch, and
Bitgood (1973) increased the duration of lever holding in
rats by reinforcing responses that exceeded a specified
duration. And DeCasper and Zeiler (1977) differentially
reinforced worktimes if they were greater than a specific
duration.

In most temporal differentiation studies, however,
several variables other than the duration of the temporal
unit itself, may have contributed to the resulting change in
behavior. For example, many temporal differentiation
studies use large fixed-ratio (FR) or variable interval (VI) schedules which in themselves produce varying interreinforcement intervals, varying IRTs, and varying work times, that in some instances, may contribute to the results (Anger, 1956; Kuch & Platt, 1976; Shimp, 1967; Zeiler, 1977). In addition, in most temporal differentiation studies, the reinforcing event is presented after many responses have occurred rather than after a single correct response (Anger, 1956; Malott & Cumming, 1964; Shimp, 1967; Williams & Shull, 1982). Since many responses are occurring at different times between reinforcer presentations, perhaps the abundance of these responses, many of which are temporally distant from reinforcement, can contribute to a lack of control by the reinforcing stimuli. And finally, researchers often fail to discriminate between PRPs and IRTs on temporal differentiation procedures. For example, Staddon (1965) attempted to increase IRT lengths. However, a reinforcing stimulus was presented if either the IRT or PRP was a specified duration. To this date there is no published research that demonstrates whether PRPs and IRTs warrant this indiscriminate grouping.

The purpose of this research was to determine if two temporal variables, IRTs and PRPs, were functionally similar. An assumption about functional similarity was made at the onset of this research. Functional similarity was assumed if it could be demonstrated that IRTs and PRPs increased and decreased in a similar fashion to an identical
differential reinforcement procedure.

To date, research has demonstrated that IRTs and PRPs are susceptible to reinforcement contingencies and can be readily changed (e.g., Anger, 1956; Catania, 1970). However, this research has examined only the IRT or PRP in isolation and used different types of temporal differentiation procedures to examine each temporal unit (Anger, 1956; Malott & Cumming, 1964; Shimp, 1967; Williams & Shull, 1982). In the procedure to be described shortly, an identical reinforcement procedure was applied to both the IRTs and PRPs of a single organism. Therefore, this procedure was the first attempt to examine both these temporal units separately within a single organism.
CHAPTER II

REVIEW OF LITERATURE

Skinner (1938) was the first to specify the distinction between two functionally different temporal units. The first type, called the "temporal discrimination from the preceding reinforcement" (p. 271) is the time from a food delivery to the first response, and has more recently been labelled the "post-reinforcement pause" or PRP. The second temporal unit, which Skinner called the "temporal discrimination from the preceding response" (p. 274) is the time between two adjacent responses and is now referred to as an interresponse time or IRT. Skinner discussed these two temporal units in terms of their discriminative effect on behavior. For example, the first temporal unit (the PRP) occurs as a result of food delivery. Evidence of this temporal discrimination is a consistent lack of responding following food delivery. Evidence of the discriminatory role of IRTs, according to Skinner, is a fairly constant rate of response, with appropriately spaced responses that are characteristic of the reinforcement schedule under consideration.

This literature review will be divided into three general sections. First, studies involving both direct and indirect manipulation of PRPs will be examined followed by a review of studies involving manipulation of IRT lengths. And finally, the theoretical significance of these
manipulations will be discussed, focusing mainly on a review of IRT reinforcement theory.

**PRP Shaping Procedures**

Few examples of the direct manipulation of PRP lengths exist in the literature; however, examples of the indirect manipulation of PRP lengths are numerous (Crossman, Heaps, Nunes & Alferink, 1974; Crossman, Trapp, Bonem & Bonem, 1985; Felton & Lyon, 1966; Neuringer & Schneider, 1968; Powell, 1968). For example, Felton and Lyon (1966) increased FR requirements from 25 to 150 responses in large sequential steps and found a corresponding increase in PRP lengths. Powell (1968) increased FR size from 15 to 160 responses in small sequential steps which resulted in an increase in PRP lengths. Powell also demonstrated that PRP lengths could be systematically decreased by reducing FR size.

In contrast, studies in which PRP length serves as the event which is differentially reinforced are few in number. Only five studies to date have been reported that specifically treat PRP length as the reinforceable unit. Church and Carnathan (1963) trained rats to respond in the presence of a discriminative stimulus (S+), which was white noise, and not to respond in its absence (S−). They then imposed a differential reinforcement of short latency (DRSL) schedule on the discrimination baseline. If subjects responded in the presence of the S+ (white noise) before a criterion time had elapsed, the subjects were reinforced. A
new trial began (S+ onset) following a 30 second ITI (S−). If responding occurred after the time interval had elapsed, the white noise was terminated and an ITI of 30 seconds occurred and was followed by a new trial. Results from this procedure showed that the frequency of short-latency responses increased over preconditioning levels only in the presence of the white noise, with little responding occurring in the absence of the noise. However, the frequency of long-latency responses also increased over baseline levels in the presence of the discriminative stimulus.

Catania (1970) used a discrete trial procedure in the attempt to both increase and decrease latencies to respond. In the first experiment, latencies were increased by using a differential reinforcement of long latencies (DRLL) schedule. Trials began following a 20 second intertrial interval (ITI). A single peck led to either reinforcement followed by the ITI or to the ITI, depending on the latency of the response. Initially, pigeons were required to wait a period of time ranging from 0.60 s to 36.4 s to receive reinforcement. Results showed that mean latencies increased up to 24 s in conjunction with the required contingency. In a second experiment, subjects were required to respond before a specified time (differential reinforcement of short latencies or DRSL) ranging from 0.48 s to 14.9 s. Results showed poor control for shorter latencies, and Catania
concluded that different temporal processes controlled DRLL and DRSL schedules.

DeCasper and Zeiler (1977) were successful in increasing PRP lengths using a conjunctive schedule. Pigeons were required to wait a specified period of time after food delivery before responding to a key. Reinforcement was delivered if subjects both completed an FR 30 schedule requirement and waited a specified period of time ranging from 5 to 80 seconds. If subjects responded before the time interval had elapsed, a key color change of 4 s occurred after completion of the FR 30 schedule and was followed by a new trial. Pause times increased as a function of the imposed time requirements. A yoked control condition, used to determine if the lowering of reinforcement density was the causal factor of the increased pause times indicated that the temporal requirements rather than the reinforcement density controlled pause durations.

Williams and Shull (1982) decreased PRP lengths by delivering food to pigeons at the completion of a FR schedule (FR 70 or FR 75) only if the initial PRP was shorter than a specified criterion time. This criterion time was selected based on a subject’s mean PRP on an FR 70 (or FR 75) baseline condition. If a subject’s PRP was longer than specified, a 4 s blackout occurred at the completion of the schedule requirement instead of food and was followed by a new trial. Unlike Catania’s (1970) results, Williams and Shull showed that PRP lengths
decreased as a function of the imposed contingency. However, Catania used a small FR (FR 1) which produced a short PRP that was difficult to decrease, perhaps because of a "floor effect".

Platt (1984) used a percentile reinforcement procedure to increase latencies to respond. Latencies of sufficient length resulted in food delivery followed by an 8 s ITI. Temporal criteria were gradually increased and reinforcement density was held constant across sessions. Results indicated that response latencies increased to an asymptotic level. A further condition, conducted to determine if reinforcement density or differential reinforcement controlled responding demonstrated that the reinforcement contingencies controlled the increase in response latencies.

Summary of PRP Shaping Literature

The research demonstrates that PRP durations can be both increased and decreased either by using indirect methods (i.e., increasing FR size), or by applying reinforcement contingencies directly to the PRP. In addition, it has been demonstrated that differential reinforcement rather than reinforcement density controls changes in PRP durations.

Introduction to IRT Literature

Anger (1954; 1956) was the first to coin the term, interresponse time. He conceptualized the IRT as the time between two responses, and demonstrated the important role
of relative reinforcement on the development of IRTs of
different lengths. Morse (1966) expanded the concept of IRT
further and described it as a functional unit of behavior
which in itself could be susceptible to reinforcement
processes.

Skinner (1938) was the first to discuss the importance
of IRTs in the control of responding. He hypothesized that
a possible explanation for the differing response rates on
FR and FI schedules was that shorter IRTs were reinforced on
FR schedules. The first research specifically manipulating
IRT lengths through the process of direct reinforcement was
reported by Skinner in 1938. He placed rats on a
differential reinforcement of low rates 15 second schedule
(DRL 15) and found that response rates decreased as a
function of the DRL contingency. Numerous studies on
manipulating IRT lengths have followed Skinner's early work.

The present literature review focuses on studies in
which IRT lengths have been directly manipulated. In other
words, the IRT is considered as the "reinforceable unit"
(Zeiler, 1977). The studies to be described can be
classified into three general categories. First, there are
studies in which the authors have attempted to increase IRT
lengths. These studies use schedules that have been
traditionally labeled differential reinforcement of low
rates or DRL schedules (Ferster & Skinner, 1957). More
recently, however, these schedules have been called
differentiation schedules and have been symbolized as
IRT > t by Zeiler (1977). The second group of studies that will be examined are differential reinforcement of high rate or DRH schedules. Zeiler (1977) symbolizes these differentiation schedules as IRT < t. And finally, the third category of studies deals with research that attempts to reinforce certain classes of IRTs. For example, reinforcement is delivered following an IRT between 1 s and 2 s in length. Each of these three areas of IRT research will be considered in turn.

**Differential Reinforcement of Low Rate Procedures**

Studies involving DRL schedules generally deliver reinforcement immediately after the required IRT occurs, or deliver reinforcement after a number of IRTs have occurred, on a specific schedule of reinforcement.

Sidman (1956) developed discriminative responding in rats on two levers. Lever A was associated with a DRL 20 s schedule and lever B was associated with a continuous reinforcement (CRF) schedule. On the average of every four minutes, an auditory stimulus was presented, signalling reinforcement availability on lever B. A response to lever B produced reinforcer delivery, a termination of the auditory stimulus, and a resetting of the DRL clock associated with lever A. Responses in the absence of the auditory stimulus on lever A were reinforced according to a DRL 20 s schedule. Results showed that subjects readily learned the discrimination; in addition, responding on the
lever associated with the DRL contingency (lever A) showed that the majority of IRTs were 16 s to 28 s in duration indicating control by the DRL schedule. However, the subjects also exhibited frequent bursts of responding as evidenced by a large number of 0 s to 2 s IRTs.

Anger (1956) established a DRL 40 s schedule in which the appropriate IRT length was reinforced on a variable-interval five minute (VI 5 min.) or on a VI 2.5 min. schedule. This schedule produced reinforcement if two events had occurred in a specific order: first, the variable-interval value had to have expired and then, an IRT of the appropriate length had to have occurred. For example, if a response terminating an IRT of 40 s or greater had previously occurred after the VI value had expired, reinforcement was delivered. Results showed that subjects exhibited a higher frequency of IRTs of 24-32 s and 32-40 s durations than during VI 5 min. or VI 2.5 min. baseline conditions. This finding was consistent for both the VI 5 min. and VI 2.5 min. conditions.

Staddon (1965) investigated a series of DRL schedules ranging from DRL 5 to DRL 30 seconds. Pigeons were reinforced immediately after an appropriate response. Responses were considered appropriate if they followed another response or reinforcer or the beginning of a session by t seconds. Rates of responding increased as the DRL requirement was decreased. Median IRT also increased as a function of the DRL contingency.
Richardson and Loughead (1974) studied very large DRL values. Pigeons and rats were tested on DRL values ranging from 1 to 45 minutes. Reinforcement was delivered if subjects either spaced responses apart by the specified time, or waited to respond for a specific period of time following a reinforcer. Results showed that mean IRT length increased as DRL requirements increased for both pigeons and rats. An examination of the relative frequency distributions of IRTs for the pigeons and the rats showed, in general, that the majority of the IRTs that occurred on a specific DRL schedule were equal to or greater in length than the required DRL durations.

Variables Proposed to Control DRL Response Rates

Several researchers have proposed that variables other than the DRL contingency itself, may control rate of response and IRT lengths. These variables include reinforcement density and probability of reinforcement. The following studies focus on holding these variables constant across various DRL contingencies.

Richardson (1973) proposed that the DRL schedule itself had no direct effect on behavior. Rather, reinforcement density was hypothesized to be the relevant variable controlling rate of response. In his study, both pigeons and rats were reinforced on a DRL 15 s schedule. Each subject in this initial condition was paired with a yoked control subject that received reinforcement on a VI
schedule. This schedule was identical in reinforcement density to the DRL 15 s schedule, but did not include the DRL contingency. The findings showed that a higher rate of response was maintained by the VI schedule as compared to the DRL schedule, even though reinforcement densities were identical on both schedules. Thus, he concluded that the DRL contingency was responsible for the lower response rate.

Alleman and Platt (1973) reinforced IRTs that occurred with very low frequencies while holding probability of reinforcement constant across conditions. They called this procedure a percentile reinforcement procedure because only a certain percentage of IRTs were being reinforced. This procedure operated by constantly shifting the IRT contingency requirements based on the organism's present IRTs. On this procedure reinforcement was delivered if an IRT was greater than or less than 95, 90, 75, and 50% of the organism's most recent IRTs. The IRT contingencies were constantly changed based on the subject's current IRTs. As each IRT occurred, it was placed in the computer's memory and a new value of the IRT contingency was calculated. Results showed that the IRT frequency distribution and response rates shifted as a function of the extreme percentage conditions (i.e., 90% and 95% conditions) but showed less change with the 50% and 75% conditions. It was concluded that the probability of reinforcement per response was not responsible for the change in IRT lengths.

An additional study by Kuch and Platt (1976) attempted
to ascertain if changes in rate of reinforcement or differential reinforcement of IRTs controlled IRT lengths. A percentile reinforcement procedure in which IRTs were reinforced on VI schedules ranging from 10 to 120 seconds was used. Two different conditions consisting of reinforcing either very short or very long IRTs (relative to a subject's previous IRT distributions) were conducted. Results showed that mean IRTs increased or decreased as a function of the imposed contingency. In addition, the relative frequency distributions showed a shift from a single peak for short IRTs during VI baseline conditions, to bimodal distributions for the reinforcement of longest IRT conditions. Also it was found that rate of reinforcement, as determined by different VI schedules, tended to affect the shape of the IRT frequency distributions. In frequency distributions from the long IRT reinforcement conditions, the second peak of the bimodal distributions tended to fall at a higher IRT value, with lower rates of reinforcement. In a second experiment, Kuch and Platt attempted to determine why the IRT distributions from the long condition had higher peaks (i.e., IRTs of longer durations) with lower reinforcement rates. Rate of reinforcement was held constant (VI 120 s) while IRTs of various lengths were reinforced. Results from this second experiment showed that differential reinforcement of IRTs rather than the rate of reinforcement was more important in determining IRT lengths.
Summary of DRL Literature

The research in this section offers conclusive evidence that selected IRT durations can be increased through the use of differential reinforcement procedures. In addition, there is evidence that eliminates both reinforcement density and reinforcement probability as alternative explanations for the results.

Differential Reinforcement of High Rate Procedures

Examples of differential reinforcement of high rates (DRH) studies are rare in the literature. The only study relevant to the present review was conducted by Anger (1956). He used a DRH 28 s schedule in which pigeons were reinforced on the average every five minutes (VI 5 min) if IRT lengths were less than 28 s in duration. For example, if both the VI value had elapsed and after this event, a response that terminated an IRT of less than 28 seconds had occurred, reinforcement was delivered. He found little or no increase in response rate, as compared to previous DRL conditions.

Differential Reinforcement of Classes of IRTs

In the third category of IRT reinforcement, IRTs of certain classes are reinforced, i.e., an upper (upper bound) and lower (lower bound) time limit are specified, and all IRTs that fall within the specified boundaries are
reinforced. Malott and Cumming (1964) examined several variables of interest using schedules of IRT reinforcement. Their first group of experiments examined both the minimum and maximum time a subject had to wait before reinforcement (DRL schedule) presentation. These times ranged from 4 s to 100 s. For example, in the 4 s condition, responses had to be spaced at least 4 s apart in order for reinforcement to be delivered. In the 100 s condition, responses had to be spaced at least 100 s apart. Each of these DRL conditions resulted in IRTs that were of sufficient length to produce reinforcement. A second group of studies examined reinforcing classes of IRTs. In addition, the widths of these classes were systematically varied. For example, if IRTs were 1.0 s to 1.5 s duration, they produced reinforcement. The width of the above mentioned IRT class would be 0.5 s (1.5 s - 1.0 s = 0.5 s). Malott and Cumming increased and decreased this width, to determine when control by the IRT class would be disrupted. As the width of the IRT class was narrowed, the IRT distributions became flatter, indicating a loss of control by the IRT reinforcement schedule under consideration. A third group of studies examined the probability of presenting a reinforcing stimulus following an appropriate IRT. These IRT probability schedules ranged from a high of 1.0 (every appropriate IRT reinforced) to a low of 0.10 (1 out of 10 appropriate IRTs being reinforced). Results showed that as the probability of reinforcement was decreased, the
frequency distributions of IRTs flattened, indicating a loss of control by the particular IRT schedule in effect.

Shimp (1967) also investigated variables associated with IRT lengths. In his study, he used what he referred to as a pacing contingency. Interresponse times of the appropriate length were reinforced on a VI 1 minute schedule. Pigeons' IRTs were reinforced if they occurred between two temporal boundaries. For example, if IRT durations were between 0.30 and 0.60 s, they were reinforced according to a VI 1 min schedule. The temporal boundaries ranged from 0.30 and 0.60 s to 1.80 to 2.40 s. The findings showed that IRT frequency distributions for all subjects shifted as a function of the required temporal contingency. However, upon return to a previously reinforced IRT class, Shimp reported a difficulty in replicating the original IRT frequency distributions.

Wilkie and Pear (1972) investigated the effects of different intermittent reinforcement schedules on specific classes of IRTs. Interresponse times ranging in durations from 1.0 to 2.0 s were reinforced on a random-interval 5.0 s schedule, on a DRL 4 s schedule, and on a random-interval 7 s schedule. Results showed that response rate and number of 1.0 to 2.0 s IRTs per second changed as a function of the reinforcement schedule in effect, with the DRL 4 s schedule maintaining lower IRT rates than either of the random-interval schedules. In a second experiment, 1.0 to 2.0 s IRTs were reinforced on various FR, FI, and RR
schedules. The findings showed that each schedule maintained characteristic patterns of emitted IRTs in the 1.0 to 2.0 s range. The authors concluded that IRTs functioned as operants and were susceptible to reinforcing contingencies in the same fashion that a response is susceptible.

**Summary of IRT Classes Literature**

The research demonstrates that classes of IRTs are also susceptible to reinforcing contingencies. In addition, it was found that IRT frequencies change in a predictable manner as a function of applying different schedules of reinforcement.

**Temporal Reinforcement Theory**

The literature abounds in theoretical explanations of the role of temporal variables, particularly IRTs, in the control of behavior. Skinner's (1938) distinction between "temporal discrimination from the preceding reinforcement" (p. 271) and "temporal discrimination from the preceding response" (p. 274), set the stage for the debate over the importance of temporal variables, a debate that continues to this date (e.g., Platt, 1984; Rider & Kametani, 1987).

The main focus of the debate is on one central issue: namely, are temporal units simply discriminative stimuli that set the occasion for particular responses, or can IRTs be thought of as functional units, that in themselves can be shaped, reinforced, and changed by direct manipulation
(Morse, 1966)? Zeiler (1977) clearly specified the conditions necessary for a behavior to be considered a functional response unit. He specified three distinct types of response units. First, the formal response unit is "the class of behavior that the experimenter prescribes as prerequisite for a reinforcer presentation" (p. 222). Examples of this type of unit are the response that an experimenter is attempting to manipulate such as a lever press, or a key peck. A second type of response unit called the conditionable unit, is a behavior that can be functionally demonstrated to increase in probability as a result of reinforcement presentations. Zeiler classified an operant in this second category. The third unit is called a theoretical unit, and is behavior that is inferred to underlie observed behavior, such as stimulus-response or cognitive activities.

Zeiler (1977) used the interresponse time as an example of behavior that can be classified as any of these three response units depending on the goals of the research in question. He states:

if the interresponse time is specified as the requirement for the delivery of a reinforcing stimulus, it is the formal unit. If it should be altered by the imposition of these consequences, it is a conditionable unit. It is a theoretical unit when it is used to explain performance under a schedule in which some other behavior is specified as the formal unit (Zeiler, 1977, p. 223).

The focus of this review is to incorporate Zeiler's definition of the conditionable unit, to determine if temporal units in themselves are capable of being
manipulated and changed. Whereas there is empirical evidence supporting this conditionable function of both IRTs (e.g., Anger, 1956; Shimp, 1967) and PRPs, (e.g., Catania, 1970; Williams & Shull, 1982) there are others who claim that there is no direct evidence for the susceptibility of IRTs to differential reinforcement (e.g., Reynolds & McLeod, 1970).

Reynolds and McLeod (1970) propose that there is no substantial evidence for IRT reinforcement theory. The basic premise of IRT reinforcement theory is that certain characteristics of emitted IRTs are somehow determined by the characteristics of those IRTs which are reinforced. They note three major areas of evidence that purport to support the theory:

1) The work of Skinner (1938) and his proposed explanation for different response rates on ratio and interval schedules;
2) Studies involving differential reinforcement of IRTs, such as DRL and DRH;
3) Anger's (1956) study which demonstrates that there is a correlation between emitted and reinforced IRTs.

The authors present evidence that directly questions each of these three areas, and that questions an IRT reinforcement explanation for the changing IRT distributions.

Reynolds and McLeod present two lines of contradictory evidence against Skinner's explanation for differing response rates on FR and FI schedules. First, if IRTs were
differentially reinforced, responding on fixed-ratio schedules logically should produce shorter and shorter IRTs, and on fixed-interval schedules, IRTs should get longer and longer. However, this clearly is not the type of temporal response patterning that occurs on these schedules (Morse, 1966). In addition, in the case of fixed-ratio schedules, IRT lengths are completely independent of reinforcement delivery, because it is the number of responses rather than their temporal placement that is the key to reinforcement delivery, hence a lack of differentiating effects.

The second line of evidence involves differential reinforcement of specific IRTs. Reynolds and McLeod state that instead of IRTs being reinforced, what is reinforced is either some other behavior that is occurring concurrent with the IRTs or a change in the topography of the response. Evidence for other behaviors occurring comes from reports of stereotyped sequences of behavior occurring during DRL performance (Latics, Weiss, Clark, & Reynolds, 1965; Wilson & Keller, 1953). Evidence for changes in response topography is lacking in the literature. However, Reynolds and McLeod explain that large amounts of behavior are often emitted on differential reinforcement schedules, that in turn change overall patterns of IRTs rather than change individual IRTs themselves (Reynolds & McLeod, 1970, p. 96-97).

The third line of evidence deals with correlations between reinforced IRTs and emitted IRTs that were
originally calculated by Anger (1956). Reynolds and McLeod (1970) claim that the correlations between the reinforced IRTs and the emitted IRTs are a mathematically-forced relationship. Through an analysis of the original work of Anger, and some further work of their own, that consisted of a replication of Anger’s original study, a more fine-grained analysis of the resulting data showed that a correlation between emitted and reinforced IRTs exists regardless of what type of emitted distribution of IRTs was being examined.

The work of Reynolds and McLeod (1970) questions what is actually occurring in the chamber during IRT reinforcement procedures. It points to the necessity of observing closely whether repeated behavior sequences or stereotyped behavior occurs rather than changed IRTs. However, it is possible that stereotyped behavior is constantly occurring in all types of reinforcement procedures. Because an unseen event (the passage of time) is occurring, often theorists compose a process of some type to bridge this time passage. For example, in problem solving, if it takes 10 seconds to solve a problem, theorists infer a thought process. During this ten-second period the "thinker" could be looking in an upward direction which could be inferred to be a stereotypic behavior. There is scant evidence that implied mediating behavior of the type just mentioned (both stereotypic and thoughtful) is useful in understanding behavior (Epstein, 1981; Epstein,
Lanza & Skinner, 1980; Skinner, 1953, 1977). If a response is separated from another response by a period of time, and it can be functionally demonstrated that the period of time can be manipulated systematically, additional explanations of what occurs are not necessary to advance an understanding of that behavior. Whereas evidence may exist for stereotypic behavior that occurs under DRL schedules, sufficient evidence also exists that the temporal period can be manipulated.

To this point the area of PRP reinforcement has largely been neglected. There is very little literature on PRP reinforcement theory, although evidence does exist that the PRP can be manipulated in similar ways to the IRT. However, no literature exists that puts both IRTs and PRPs as temporal units into an identical realm. If it can be demonstrated that IRTs and PRPs are equally susceptible to similar contingencies, then IRT and PRP reinforcement theory could be expanded greatly. The first step would be to discontinue the use of the term IRT reinforcement theory and instead use the term temporal reinforcement theory. This new terminology would incorporate both IRTs and PRPs and, in addition, could include other temporal variables that have not been the focus of this review, such as response duration, work time, and any other temporal processes that have yet to be determined to be important to the understanding of behavior. If it can be demonstrated that all these temporal units are similarly conditionable, then
perhaps a general theory which encompasses these units can be developed. If these temporal units are not similarly affected by reinforcement contingencies, then perhaps it will be necessary to propose different theories for each type of unit.
Purpose of this Research

The preceding review of the literature indicates that differentiation procedures have demonstrated that both IRT and PRP durations can be manipulated (Anger, 1956; Catania, 1970). However, to this date, manipulations of both the PRP and IRT have not been demonstrated within a single subject. In addition, different procedures have been used to manipulate these temporal units. Therefore, the purpose of this research was to determine if IRTs and PRPs show similar duration changes within a single subject. An identical differentiation procedure was applied to each of these temporal units. However, each of these temporal units was manipulated separately. For example, differential reinforcement was applied first to IRT durations in a subject followed by differential reinforcement of PRP durations in the same subject.

A possible confounding variable of the shaping procedure used was that in differentially reinforcing one type of temporal unit, the other type of temporal unit could have been effected. Thus, an additional purpose of this research was to examine how shaping one temporal unit effected the other temporal unit. Several effects were possible:

1) On IRT shaping the PRP will also change.
2) On IRT shaping the PRP will remain unchanged (as compared to baseline levels).
3) On PRP shaping the IRT will also change.
4) On PRP shaping the IRT will remain unchanged (as compared to baseline levels.)

A determination of the presence (or absence) of interactions between these temporal units is important to generating a theory of temporal conditioning.
CHAPTER III

EXPERIMENT 1: MANIPULATION OF IRT AND PRP DURATIONS THROUGH THE USE OF DIFFERENTIAL REINFORCEMENT WITH A FIXED-RATIO TWO RESPONSE REQUIREMENT

Experiment 1 examined the effects of differential reinforcement on the PRP and IRT durations of pigeons on an FR 2 schedule. This simple ratio schedule was selected for two reasons. First, it was important that only a single IRT was allowed to occur before a consequence was applied. As mentioned earlier, in many other procedures used to shape IRT lengths, numerous IRTs of both incorrect and correct durations occurred before a consequence was applied. This presents a complicated situation because of the possible sequential interactions that could have occurred. Thus, a basic consideration of the proposed research was that either a reinforcing stimulus or a blackout be delivered after every IRT that occurred to insure that the behavior would be consequated immediately, thereby increasing the likelihood of relating behavior change to the procedure in effect. Concentrating on a schedule with a single IRT should reduce, or eliminate, complex IRT interactions.

Second, only a single PRP (followed by one IRT) was allowed to occur on this simple schedule before a consequence was delivered. After the PRP (and one IRT) occurred, either a reinforcing stimulus or a blackout was presented immediately. Once again, it was critical to the goals of this research that consequences for both IRTs and
PRPs be delivered after one PRP and one IRT, to maximize the effects of the reinforcing stimulus and to reduce the possibility of schedule interactions.

Method

Subjects

Four experimentally naive homing pigeons of undetermined sexes and ages served as subjects. An initial weight under the conditions of free food and water was calculated for each subject. A subject's weight was subsequently reduced to 80% of its free-feed weight. A subject was used in a particular session only if its daily weight was within 5% of its 80% weight. Supplemental feeding occurred in the home cage immediately following a session if a bird's pre-session weight dropped below 5% of its 80% weight. Water and grit were freely available in the home cage at all times.

Apparatus

The experiment was conducted in a one-key operant chamber. The interior chamber dimensions were 32 cm (height) X 26 cm (width) X 28.5 cm (length). The key, which was transilluminated with a red light, was located on the front panel 20.5 cm above the chamber floor and centered 11.5 cm from each wall. The key was 2.5 cm in diameter. The houselight, which was lit by a single Archer #1819 bulb, was centered on the front panel 29.5 cm above the chamber floor, and 12 cm from each wall. The food hopper, also on
the front panel, was located 6.5 cm above the chamber floor, and 10.5 cm from each chamber wall. The food hopper opening measured 5.0 cm. Peterson-Biddick mixed-grain pigeon feed was used as the reinforcer.

A Commodore (Commodore Business Machines, Inc.) 64 computer in conjunction with a custom-built interface (Crossman, 1984) controlled the experimental manipulations through the use of BASIC programming. The data were stored on a Commodore 1541 disk drive, and analyzed on the Commodore 64/1541 system. Temporal events were recorded with an accuracy of 1/60 second.

Procedure

For clarification purposes, the following terms will be used to describe the experimental manipulations:

Initial training - Training which involved shaping initial pecks to the key.

Condition - Used to distinguish across baseline, IRT shaping, and PRP shaping experimental manipulations.

Procedure - Used to distinguish across varying manipulations within a condition.

Shaping procedure - Used to distinguish across specific temporal contingencies within a procedure.

Initial training. Initial training consisted of hand shaping each subject to peck the red key. After the first reinforced key peck occurred, the next nine key pecks were each followed by reinforcer delivery. On the day following
this initial training, subjects were started on the baseline condition.

Experimental design. It is possible that being exposed to IRT shaping (or PRP shaping) first could influence later exposure to the opposite condition. Therefore, to control for possible sequence effects, the four subjects were randomly assigned to one of two groups. Group 1 received the following procedures (each procedure is described in detail below): FR 2 baseline, FR 2 PRP > t, FR 2 PRP < t, FR 2 baseline, FR 2 IRT > t, FR 2 IRT < t, and FR 2 baseline. Group 2 received FR 2 baseline, FR 2 IRT > t, FR 2 IRT < t, FR 2 baseline, FR 2 PRP > t, FR 2 PRP < t, and FR 2 baseline. Table 1 shows each procedure, order of presentation and number of sessions on each procedure for each subject in group 1. Table 2 shows procedures for each subject in group 2.

FR 2 baseline condition. Baseline consisted of exposing the four subjects to a fixed-ratio 2 (FR 2) schedule. Trials started with keylight and houselight onset. A reinforcement cycle of three seconds followed two pecks to the key. The keylight was extinguished during reinforcement cycles. After the reinforcement cycle, all chamber lights were extinguished for three seconds (3 s intertrial interval or ITI) followed by a new trial. Sessions terminated after 40 reinforcements. Subjects continued on this baseline condition for a minimum of ten sessions or until stable responding had developed. Stable responding was defined as
Table 1

*Each Procedure, Order of Presentation and Number of Sessions on Each Procedure for Each Subject in Group One*

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number of Sessions</th>
<th>Procedure</th>
<th>Number of Sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR 2 Baseline</td>
<td>24</td>
<td>FR 2 Baseline</td>
<td>35</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 0.75 s</td>
<td>3</td>
<td>FR 2 PRP &gt; 1.25 s</td>
<td>11</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 1.25 s</td>
<td>5</td>
<td>FR 2 PRP &gt; 2.90 s</td>
<td>25</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 1.90 s</td>
<td>9</td>
<td>FR 2 PRP &gt; 3.90 s</td>
<td>22</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 2.90 s</td>
<td>28</td>
<td>FR 2 PRP &lt; 3.90 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 2.90 s</td>
<td>3</td>
<td>FR 2 PRP &lt; 2.90 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.90 s</td>
<td>1</td>
<td>FR 2 PRP &lt; 1.25 s</td>
<td>2</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.25 s</td>
<td>1</td>
<td>FR 2 Baseline</td>
<td>25</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 0.75 s</td>
<td>6</td>
<td>FR 2 IRT &gt; 0.63 s</td>
<td>36</td>
</tr>
<tr>
<td>FR 2 Baseline</td>
<td>19</td>
<td>FR 2 IRT &gt; 1.92 s</td>
<td>14</td>
</tr>
<tr>
<td>FR 2 IRT &gt; 0.35 s</td>
<td>36</td>
<td>FR 2 IRT &lt; 1.92 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 2 IRT &lt; 0.35 s</td>
<td>1</td>
<td>FR 2 IRT &lt; 0.63 s</td>
<td>4</td>
</tr>
<tr>
<td>FR 2 Baseline</td>
<td>11</td>
<td>FR 2 Baseline</td>
<td>14</td>
</tr>
</tbody>
</table>
Table 2

Each Procedure, Order of Presentation and Number of Sessions on Each Procedure for Each Subject in Group Two

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number of Sessions</th>
<th>Procedure</th>
<th>Number of Sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR 2 Baseline</td>
<td>14</td>
<td>FR 2 Baseline</td>
<td>16</td>
</tr>
<tr>
<td>FR 2 IRT &gt; 0.30 s</td>
<td>8</td>
<td>FR 2 IRT &gt; 0.35 s</td>
<td>2</td>
</tr>
<tr>
<td>FR 2 IRT &gt; 0.93 s</td>
<td>15</td>
<td>FR 2 IRT &gt; 0.65 s</td>
<td>13</td>
</tr>
<tr>
<td>FR 2 IRT &lt; 0.93 s</td>
<td>1</td>
<td>FR 2 IRT &gt; 1.00 s</td>
<td>16</td>
</tr>
<tr>
<td>FR 2 IRT &lt; 0.30 s</td>
<td>9</td>
<td>FR 2 IRT &lt; 1.00 s</td>
<td>2</td>
</tr>
<tr>
<td>FR Baseline</td>
<td>18</td>
<td>FR 2 IRT &lt; 0.65 s</td>
<td>2</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 1.45 s</td>
<td>29</td>
<td>FR 2 IRT &lt; 0.35 s</td>
<td>25</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 2.63 s</td>
<td>20</td>
<td>FR 2 Baseline</td>
<td>27</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 2.63 s</td>
<td>1</td>
<td>FR 2 PRP &gt; 0.70 s</td>
<td>7</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.45 s</td>
<td>3</td>
<td>FR 2 PRP &gt; 1.13 s</td>
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</tr>
<tr>
<td>FR 2 Baseline</td>
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<td>FR 2 PRP &gt; 1.00 s</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FR 2 PRP &lt; 1.88 s</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FR 2 PRP &lt; 1.13 s</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FR 2 PRP &lt; 0.70 s</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FR 2 Baseline</td>
<td>19</td>
</tr>
</tbody>
</table>
the lack of an upward or downward trend in both mean post-reinforcement pause (PRP) and in mean interresponse time (IRT) for the last five sessions of the baseline condition. In addition, a new high or low mean IRT or PRP could not occur during the last five sessions. If a new high or low occurred, the subject was continued at least an additional five days on the baseline condition. This stability criterion was used for all subsequent baseline (but only baseline) conditions throughout the experiment.

**FR 2 PRP > t procedure.** To determine the starting temporal criterion, a relative frequency distribution of PRPs for each subject on the last session of the FR 2 baseline condition was calculated. A criterion PRP length was selected for each subject dependent on this frequency distribution. This criterion PRP was the lower bound of the upper 20% of the PRP distribution. In other words, the first PRP criterion was the value located at the 80th percentile of the distribution.

This PRP temporal criterion was used in the first shaping procedure. This shaping procedure began with illumination of the red key and houselight, and a time interval (the PRP temporal criterion interval) was initiated. If a peck occurred after the PRP criterion interval had elapsed, the trial was identical to the baseline condition, i.e., two pecks led to reinforcement followed by a three-second ITI (all lights off) and a new trial. If a peck occurred before the PRP criterion interval
had elapsed, the keylight and houselight were immediately extinguished for six seconds (6 s blackout). A six-second blackout was used to help equate the times on reinforced and nonreinforced trials. On reinforced trials, food delivery and ITI were both three seconds in duration; therefore, the six-second blackout was used on nonreinforced trials. A session terminated after 40 reinforcements.

Subjects continued on the first PRP shaping procedure until one of the following criteria were met:

1) Fewer than 20 nonreinforced trials occurred in a session.
2) No new high mean PRP had occurred in the previous 10 sessions (i.e., mean PRPs under the current PRP shaping procedure were compared across sessions).

If criterion 1 was met, the subject was continued on a second shaping procedure (e.g., FR 2 PRP > 1.0 s to FR 2 PRP > 2.0 s). If criterion 2 was met, the subject was moved to the next scheduled procedure (i.e., FR 2 PRP > t to FR 2 PRP < t) in the following session.

To calculate the new criterion time on the second shaping procedure, a PRP relative frequency distribution of the last session on the first shaping procedure was calculated and the lower bound of the upper 20% of the distribution was used as the new criterion PRP. Subsequent temporal criteria were calculated on the last session of the preceding shaping procedure. Subjects continued on the FR 2 PRP > t procedure until criterion 2 occurred or until the
PRP had been increased (through shaping procedures) by 300% over baseline levels. These criteria were arbitrarily chosen so as to produce easily distinguishable patterns of responding at each of the shaping conditions.

**FR 2 PRP < t procedure.** This procedure was identical to the FR 2 PRP > t procedure, except that a nonreinforced trial occurred only if the subject pecked the key after a specified period of time had elapsed. Reinforcement was delivered following two pecks if the initial peck occurred before a specified PRP criterion interval had elapsed. The PRP criterion intervals were the same intervals used in the FR 2 PRP > t shaping procedures, except in reverse order (e.g., if criterion intervals for FR 2 PRP > t had been 1 s, 2 s, 3 s, 4 s; then for the FR 2 PRP < t procedure, they would be 4 s, 3 s, 2 s, and 1 s). Subjects were continued on the first FR 2 PRP < t shaping procedure until one of the following criteria were met:

1) Fewer than 20 nonreinforced trials occurred in a session.

2) No new low mean PRP had occurred in the previous 10 sessions.

If criterion 1 was met, the subject was continued on the second shaping procedure (e.g., FR 2 PRP < 4.0 s to FR 2 PRP < 3.0 s). If criterion 2 was met, the subject was started on the next scheduled procedure (i.e., FR 2 PRP < t to FR 2 baseline) in the following session.

**FR 2 IRT > t procedure.** This procedure began with
illumination of the houselight and the red key. After the first peck to the key, an IRT criterion interval began to time. If the subsequent peck (the second response) occurred after the IRT criterion interval had elapsed, reinforcement was delivered. After a three second ITI (all lights off) following reinforcement, a new trial began. If the second peck occurred before the IRT criterion interval had elapsed, a six-second blackout occurred, followed by a new trial.

To determine the starting shaping criterion, a frequency distribution of IRTs from a subject's last session on the immediately preceding FR 2 baseline condition was calculated. The initial IRT criterion interval was the lower bound of the upper 20% of the IRT frequency distribution (80th percentile).

Subjects continued on the first IRT shaping procedure until one of the following criteria were met:

1) Fewer than 20 nonreinforced trials occurred in a session.

2) No new high mean IRT had occurred in the previous 10 sessions.

If criterion 1 was met, the subject was continued on a second shaping procedure (e.g., FR 2 IRT > 0.50 s to FR 2 IRT > 0.75 s). If criterion 2 was met, the subject was moved to the next scheduled procedure (i.e., FR 2 IRT > t to FR 2 IRT < t) in the following session.

To calculate the new criterion time for the second shaping procedure, an IRT frequency distribution of the last
session on the first shaping procedure was calculated and the lower bound of the upper 20% of the distribution was used as the new criterion IRT. Subsequent temporal criteria were calculated on the last session of the preceding shaping condition. Subjects were continued on the FR 2 IRT > t procedure until criterion 2 occurred or until the IRT had been increased 300% over baseline levels.

FR 2 IRT < t procedure. This procedure was similar to the IRT > t procedure, except that reinforcement was delivered if the time between two responses was less than the specified IRT criterion interval. A nonreinforced trial resulted if the time between two responses was greater than the specified IRT criterion interval. The IRT criterion intervals were the same intervals used in the FR 2 IRT > t procedure, except in reverse order of presentation. Subjects continued on the first IRT shaping procedure until one of the following criteria were met:

1) Fewer than 20 nonreinforced trials occurred in a session.
2) No new low mean IRT had occurred in the previous 10 sessions.

If criterion 1 was met, the subject was continued on the second shaping procedure (e.g., FR 2 IRT < 0.75 s to FR 2 IRT < 0.50 s). If criterion 2 was met, the subject was started on the next scheduled procedure (i.e., FR 2 IRT < t to FR 2 baseline) in the following session.
**Results and Discussion**

All subjects completed initial training within two sessions. There was no apparent difference between delivering either the PRP shaping or IRT shaping condition first; therefore, the data are presented independent of the sequence of condition delivery.

The dependent variables were mean PRP and IRT of the last session of each baseline and shaping procedure. Standard deviations of PRPs and IRTs were also calculated for last sessions. Relative-frequency distributions of PRPs and IRTs for the same last sessions were also calculated. In addition, the number of nonreinforced trials across all PRP and IRT shaping procedures were compared. The terms, "direct" and "indirect" effects, are used throughout. Direct effects are those changes in behavior that occurred as a result of the behavior specified by the contingency. Indirect effects are those changes that occurred in scheduled behaviors that were not specified by the contingency. For example, in the FR 2 PRP shaping condition, changes in PRP lengths are referred to as a direct effect; changes in the IRT lengths (in the same FR 2 PRP shaping condition), however, are considered indirect effects.

**Direct Effects**

Figure 1 presents relative frequency distributions of PRPs (left panel) and IRTs (right panel) as a function of
Figure 1. Relative frequency distributions of PRPs and IRTs as a function of the direct effects of PRP and IRT shaping under FR 2 for Bird B2.
**PRP CONDITIONS**

- **FR 2**
  - $X = 5.7\ s$
  - $SD = 2.2$

- **> 0.75 s**
  - $X = 5.6\ s$
  - $SD = 3.4$

- **> 1.25 s**
  - $X = 5.4\ s$
  - $SD = 3.6$

- **> 1.90 s**
  - $X = 5.3\ s$
  - $SD = 3.8$

- **> 2.90 s**
  - $X = 5.5\ s$
  - $SD = 4.0$

- **< 2.90 s**
  - $X = 5.14\ s$
  - $SD = 1.07$

- **< 1.90 s**
  - $X = 5.5\ s$
  - $SD = 3.8$

- **< 1.25 s**
  - $X = 5.0\ s$
  - $SD = 1.9$

- **< 0.75 s**
  - $X = 5.5\ s$
  - $SD = 3.3$

- **FR 2**
  - $X = 6.6\ s$
  - $SD = 2.4$

**BIRD B2**

**IRT CONDITIONS**

- **FR 2**
  - $X = 2.28\ s$
  - $SD = 1.1$

- **> 0.55 s**
  - $X = 2.34\ s$
  - $SD = 1.8$

- **> 0.75 s**
  - $X = 2.59\ s$
  - $SD = 1.7$

**BINS (.04999 s)**

- **FR 2**
  - $X = 2.28\ s$
  - $SD = 1.1$

- **> 0.55 s**
  - $X = 2.34\ s$
  - $SD = 1.8$

- **> 0.75 s**
  - $X = 2.59\ s$
  - $SD = 1.7$

**BINS (.04999 s)**
the direct effects of PRP and IRT shaping under FR 2 for Bird B2. The data are from the last session of each baseline and shaping procedure. A distribution was determined by first calculating the durations of each PRP and IRT that occurred within the session being examined. Each IRT and PRP was then assigned a location within a temporal category, referred to as a bin. For the PRP distributions, bin sizes were 0.2499 s in width. For example, bin 1 contained PRPs ranging in size from 0.0001 s to 0.2499 s. Bin 2 contained PRPs of 0.2500 s to 0.4999 s, bin 3 contained PRPs of 0.5000 s to 0.7499 s, etc. The 40th bin contained all PRPs greater than 9.7500 s. After each PRP was assigned a location within a bin, the number of PRPs within a particular bin relative to the total number of PRPs present in the session was calculated as a percentage. The result is a distribution of PRPs that can be compared across all shaping procedures. Bin size for IRTs was 0.0499 s in width, and the 40th bin contained IRTs greater than 1.9500 s. Bin size was held constant across all relative frequency distributions presented in each figure.

The label in the upper right corner of each distribution in Figure 1 indicates which procedure (baseline or shaping) was in effect for that distribution. Directly under this label is the mean PRP or IRT and standard deviation for the session. The numeric label in the upper left corner of the first distribution on the left panel (1) indicates order of presentation.
Several criteria were used to determine if there was a change in temporal lengths as a function of the differential reinforcement contingencies. First, each relative frequency distribution was inspected visually to determine if there were changes in the percentages of PRPs or IRTs within each bin. In addition, the mean and mode of each distribution was examined for change. A change was considered to have occurred if the mean PRP or IRT had increased (or decreased) as compared to the previous distribution’s PRP or IRT and if there was a change in the mode. If the mode had changed to a higher numbered bin (as compared to the mode of the previous distribution) an increase in temporal durations was considered to have occurred. If the mode had changed to a lower numbered bin (as compared to the mode of the previous distribution) a decrease in temporal durations was considered to have occurred.

This first distribution shows the mode in bin 3. The second distribution, directly below distribution 1, shows that as the temporal contingency was applied (FR 2 PRP > 0.75 s), the PRPs showed an increase in duration as evidenced by an increased mean PRP and a change in the mode to bin 4. The second distribution also has a dotted line located at the boundary between bins 3 and 4. This line shows the point at which reinforced PRPs are separated from nonreinforced PRPs. The labels NO SR+ and SR+ indicate that the PRPs to the right of the dotted line received reinforcement (SR+) and those to the left did not (NO SR+).
The next three distributions indicate that as the PRP temporal criteria were changed, the mean and modal PRPs increased. The asterisk in distribution 5 (upper left) indicates a shaping procedure in which criterion 2 was met (i.e., the subject showed no increase in mean PRP for 10 consecutive sessions, resulting in a change to the next scheduled procedure, FR 2 PRP < t).

An additional point worth noting in the first 5 PRP distributions is that variability in PRPs increased as compared to variability during baseline. An increase in variability is exhibited by an increase in the standard deviations, by PRPs that occur within an increased number of bins and a reduction of the kurtosis of the distribution (i.e., fewer PRPs falling within a particular bin). In distribution 6, the data displayed are from the FR 2 PRP < 2.90 s shaping procedure. In this procedure, PRPs were reinforced if they were shorter than the specified criterion time. Note that reinforced PRPs are to the left of the dotted line, and nonreinforced PRPs are to the right in this and in subsequent "less than" shaping procedures. Distribution 6 shows a decrease in mean PRP as compared to distribution 5. Distributions 7 through 9 also show a decrease in mean PRP; however, the decrease is not systematic. The mode of the distribution was located in bin 3 for each of these distributions. Distribution 10, corresponds in shape to distribution 1, showing that PRPs returned to similar durations in the second FR 2 baseline
condition. A comparison of all 10 distributions indicates that PRPs showed an orderly change across all shaping contingencies.

The right panel of Figure 1 presents the IRT distributions from the IRT shaping procedures for Bird B2. Distribution 1 shows a unimodal distribution for the FR 2 baseline condition. Distribution 2 shows a slight increase in mean IRT and standard deviation when the shaping contingency was imposed. The asterisk indicates that criterion 2 was met during this shaping procedure, resulting in a change to the FR 2 IRT < 0.35 s shaping procedure. Mean IRT decreased slightly in distribution 3. Distribution 4 shows IRTs from the second baseline condition. Comparing this distribution to the first baseline condition (distribution 1) indicates slightly greater variability during the second baseline, although the mean IRTs are about the same. The modal IRT remained constant across all four distributions. A comparison of all four distributions demonstrates only modest change in IRTs across shaping procedures.

Figure 2 presents the relative frequency distributions of PRPs and IRTs as a function of the direct effects of PRP and IRT shaping under FR 2 for Bird B7. Referring first to the PRP distributions, it can be seen that distribution 1 has a unimodal shape with little variability. Mean and modal PRP increased systematically across the first three shaping procedures. Variability also showed an increase;
Figure 2. Relative frequency distributions of PRPs and IRTs as a function of the direct effects of PRP and IRT shaping under FR 2 for Bird B7.
however, the increase was not systematic. It should be noted that Bird B7 met criterion 2 under the FR 2 PRP > 3.90 s shaping procedure and was switched to the PRP < t procedure on the next session. Distribution 5 shows that as the procedure was changed from PRP > t to PRP < t there was an immediate decrease in both the mean and modal PRP. The standard deviation also decreased in distribution 5 as compared to the PRP > 3.90 s shaping procedure. The mean and standard deviation continued to decrease in the next two shaping procedures. The mode decreased from distribution 5 to 6 but remained stable across the next two shaping procedures. Distribution 8 shows PRPs on the second baseline condition. This distribution approximates the shape of distribution 1, indicating similar PRPs on the two baseline conditions. A comparison of all eight distributions indicates that mean PRP lengths changed in accordance with the various shaping procedures.

The right panel of Figure 2 presents the IRT distributions for Bird B7. Distribution 1 shows moderate variability in IRTs on the baseline condition. Distribution 2 shows an increase in mean and modal IRT and standard deviation as the first shaping procedure is imposed. Distribution 3 shows a continued increase in standard deviation on the FR 2 IRT > 1.92 s shaping procedure, and an increased mean IRT. Under this shaping procedure, however, criterion 2 was met and B7 was switched to the FR 2 IRT < t procedure. Distributions 4 and 5 show decreasing mean and
modal IRTs and standard deviations. Distribution 6, which shows IRTs from the second baseline condition, indicates little variability in IRTs and a lower mean and modal IRT, as compared to the first baseline condition. A comparison across all six distributions indicates that for this bird, IRTs were sensitive to the various shaping procedures.

Figure 3 presents the relative frequency distributions of PRPs and IRTs as a function of the direct effects of PRP and IRT shaping under FR 2 for Bird B6. Referring first to the PRP distributions, shows that distribution 1 (baseline condition) was multimodal. Distributions 2 and 3 show that when the PRP shaping procedure was applied, modal PRPs increased. Mean PRP increased in distribution 2 and remained stable in distribution 3. Standard deviation increased in distribution 2 but decreased in distribution 3. Note that Bird B6 met criterion 2 on the PRP > 2.63 s shaping procedure and was switched to the PRP < t procedure. Distributions 4 and 5 show that mean and modal PRPs and standard deviations decreased across these two shaping procedures. Distribution 6 displays PRPs from the second baseline condition and shows greater variability of PRPs and a slightly larger mean PRP than during the first baseline condition. A comparison of all six distributions shows that both mean and modal PRPs changed as a function of the imposed shaping procedures.

The right panel of Figure 3 presents IRT distributions for Bird B6. Distribution 1 has an extreme unimodal shape
Figure 3. Relative frequency distributions of PRPs and IRTs as a function of the direct effects of PRP and IRT shaping under FR 2 for Bird B6.
PRP CONDITIONS

BIRD B6

IRT CONDITIONS

BINS (.24999 s)
with the majority of IRTs falling within bin 6. Applying the first shaping procedure (FR 2 IRT > 0.30 s) resulted in an increase in the mean IRT and standard deviation but no change in the modal IRT. Distribution 3 shows a slight increase in mean IRT with no change occurring in modal IRT and the standard deviation remained stable. Criterion 2 was met under this condition; therefore, Bird B6 was switched to the FR 2 IRT < t procedure. Distribution 4 shows a decrease in standard deviation and mean IRT; however, modal IRT increased slightly. Distribution 5 shows a decrease in mean and modal IRT with a slight increase in variability. Distribution 6, which shows the second baseline condition, indicates a greater mean IRT and standard deviation as compared to the first baseline condition shown in distribution 1. Comparing across all six distributions shows an orderly change in mean IRTs across the first five procedures. However, a greater mean IRT was present on the second baseline condition.

Figure 4 presents the relative frequency distributions of PRPs and IRTs as a function of the direct effects of PRP and IRT shaping under FR 2 for Bird B8. The left panel of Figure 4 shows that distribution 1 is unimodal. Distributions 2 through 4 show that mean and modal PRPs increased across shaping procedures. There was no systematic change in standard deviations, however. Distribution 5 indicates that as the FR 2 PRP < 1.88 s shaping procedure was applied, both mean and modal PRP
Figure 4. Relative frequency distributions of PRPs and IRTs as a function of the direct effects of PRP and IRT shaping under FR 2 for Bird B8.
decreased. The standard deviation also decreased. This trend in mean PRPs continues across distributions 6 and 7. Modal PRPs remained stable, however. Distribution 8 shows the distribution of PRPs from the second baseline condition. The majority of PRPs fall within bins 2 and 3, as is the case in the first baseline condition as shown in distribution 1. Mean PRP was higher, however, under the second baseline condition. A comparison across all 8 distributions shows an orderly change in mean PRPs as a function of the PRP shaping procedures.

The right panel of Figure 4 presents the IRT distributions for Bird BB. Distribution 1 is unimodal. Distribution 2 shows that applying the FR 2 IRT > 0.35 s shaping procedure resulted in an increase in mean and modal IRTs. The standard deviation showed only a slight increase, however. The mean IRT for this shaping procedure was 0.44 s. Note that an unusually large IRT, 111.25 s, was omitted from the calculation of the mean and standard deviation due to its atypical magnitude. Mean and modal IRTs and standard deviations continued to increase across the next two shaping procedures. Distribution 5 shows that as the FR 2 IRT < 1.0 s shaping procedure was applied, variability decreased slightly and mean and modal IRTs also showed a decrease. This trend continued for distributions 6 and 7. Distribution 8 shows a unimodal shape similar to distribution 1, upon return to the baseline condition. A comparison across all eight distributions shows an orderly
change in distribution shapes and mean IRTs as a function of the shaping procedures.

With the exception of the IRT distributions for B2, which showed only slight change, the PRP and IRT distributions for all birds in Experiment 1 demonstrably shifted in accordance with differential reinforcement as specified by the various contingencies. These are the direct effects. It was also observed that in those cases where the distributions shifted in the direction of longer PRPs or IRTs the variability of the respective measures increased. In most cases this variability appeared as an increase in the number of bins containing an entry on the reinforced side of the distribution. For example, in Figure 4, when the contingency was changed from FR 2 IRT > 0.35 s to FR 2 IRT > 0.65 s (distributions 2 and 3) much longer IRTs appeared in the FR 2 IRT > 0.65 s distribution than had appeared in the FR 2 IRT > 0.35 s distribution. It was also true that as the shaping contingency was applied to shorter PRPs or IRTs, the variability decreased.

The increase in variability with longer PRPs and IRTs is interesting because it was not precisely dictated by the contingency. The contingency simply states that all IRTs > t will be reinforced. Rather than collecting around the value of t, which would tend to minimize the time to reinforcement, many of the IRTs were disseminated in the much longer IRT bins. This phenomenon will be referred to as "overcompensation."
At the same time that these longer IRTs began to appear, some of the shorter IRTs began to disappear. Both changes contributed to an increase in the mean IRT in this particular example. In spite of this loss of shorter IRTs, however, the percentage of IRTs on the unreinforced side of the distribution remained about the same because of the criterion used in this study which specified that a shift to the next procedure did not occur until fewer than 20 nonreinforced IRTs or PRPs occurred within a session. The analysis presented above for changes in the IRTs also applies to the changes in PRPs as well (see Figures 1-4).

The decrease in variability across conditions in which IRT < t and PRP < t shaping procedures were employed probably represents a "floor" effect. That is, these IRTs and PRPs were approaching their minimum possible values.

Indirect Effects

Figures 1 through 4 demonstrated how PRPs and IRTs changed as a function of the direct application of differential reinforcement to the appropriate temporal behavior. Note, however, that each of the shaping procedures described above contained both an IRT and PRP. For example, on the FR 2 IRT > t shaping procedure, a PRP was followed by an IRT. If the IRT was of sufficient duration, reinforcement was delivered. If the IRT duration was too short, a six second blackout occurred. In the above described procedure, PRP length was free to vary on both reinforced and nonreinforced trials. Reinforcement delivery
was independent of PRP duration. By the same token, in the PRP shaping procedure, IRTs were free to vary. Reinforcement delivery was independent of IRT durations.

(Note - An IRT did not occur on nonreinforced trials in the PRP shaping procedures because the 6 s blackout was delivered immediately following the first peck). How each of these temporal units changed (or did not change) when free to vary is important to the understanding of a comprehensive theory of temporal conditioning. Figures 5 through 8 show how PRPs and IRTs changed across the shaping procedures when they were free to vary. All distributions show data from the last session of each baseline and shaping condition.

Figure 5 presents the relative frequency distributions of IRTs and PRPs as a function of the indirect effects of PRP and IRT shaping under FR 2 for Bird B2. IRT distributions (under PRP shaping procedures) are shown in the left panel of the figure and PRP distributions (under IRT shaping procedures) are shown in the right panel. The upper distribution of the left panel shows IRTs from the first PRP baseline condition. The label in the upper right corner of the first distribution indicates the procedure name and the mean IRT and standard deviation for the session is directly under the name.

Distribution 1 is unimodal with some variability. When the FR 2 PRP > 0.75 s shaping procedure was imposed, mean IRT decreased slightly. No systematic change in mean or
Figure 5. Relative frequency distributions of IRTs and PRPs as a function of the indirect effects of PRP and IRT shaping under FR 2 for Bird B2.
FRP CONDITIONS

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BIRD B2

IRT CONDITIONS

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BINS (.04999 s)
modal IRTs or standard deviations is apparent across the next three shaping procedures. Distribution 6 shows IRTs on the FR 2 PRP < 2.90 s shaping procedure. Little change in the distribution is apparent as compared to the previous shaping procedure. Distributions 7, 8 and 9 show only slight changes in mean and modal IRTs and standard deviations across the shaping procedures. Distribution 10 indicates similar mean and modal IRTs as compared to the first baseline condition shown in distribution 1. A comparison of all 10 distributions indicates that as the FR 2 PRP shaping procedures were applied, there were no systematic changes in mean or modal IRTs and standard deviations across the shaping procedures.

The right panel of Figure 5 presents distributions of PRPs. Distribution 1, which shows PRPs during the first IRT baseline condition, has a unimodal shape. Distribution 2 shows increased variability as the FR 2 IRT > 0.35 s shaping procedure was applied. Mean and modal PRPs also both increased. In distribution 3 mean PRP and standard deviation decreased. The modal PRP remained constant, however. Distribution 4 shows PRPs from the second baseline condition. Variability was greater and mean PRP was similar as compared to the first baseline condition. A comparison across all four distributions indicates that mean PRPs first increased and then decreased as a function of the FR 2 IRT > t and FR 2 IRT < t shaping procedures.

Figure 6 presents the relative frequency distributions
**Figure 6.** Relative frequency distributions of IRTs and PRPs as a function of the indirect effects of PRP and IRT shaping under FR 2 for Bird B7.
PRP CONDITIONS

BIRD B7

IRT CONDITIONS

BINS (.04999 s)

BINS (.24999 s)
of IRTs and PRPs as a function of the indirect effects of PRP and IRT shaping under FR 2 for Bird B7. The left panel of Figure 6 shows the IRT distributions. Distribution 1 shows moderate variability on the FR 2 baseline condition. Distributions 2 through 4 show that as the FR 2 PRP > shaping procedures were applied, only slight changes in mean IRTs and standard deviations were apparent. Distributions 5 through 7 also show only slight changes as the FR 2 PRP < shaping procedures were applied. Distribution 8 (return to FR 2 baseline) shows an increased mean IRT and standard deviation as compared to the first baseline condition. A comparison across all 8 distributions demonstrates that as the shaping procedures were applied, little change in mean IRTs and standard deviations were apparent.

The right panel of Figure 6 presents PRP distributions. Distribution 1 shows PRPs on the first baseline condition. The distribution is unimodal. Distribution 2 shows that mean and modal PRPs and standard deviation increased as a function of applying the FR 2 IRT > 0.63 s shaping procedure. This trend continues on the next shaping procedure. Distribution 4 shows PRPs during the FR 2 IRT < 1.92 s shaping procedure. Both mean and modal PRPs and standard deviation have decreased as compared to the previous shaping procedure. A further decrease in mean and modal PRP occurred on the next shaping procedure. Standard deviation increased slightly, however. Distribution 6 shows a unimodal distribution and is similar in shape to
distribution 1. A comparison across distributions demonstrates that mean and modal PRPs first increased and then decreased across the shaping procedures in accordance with the contingency on IRTs.

Figure 7 presents the relative frequency distributions of IRTs and PRPs as a function of the indirect effects of PRP and IRT shaping under FR 2 for Bird B6. The left panel shows IRT distributions. Distribution 1 indicates moderate variability. Little change is apparent in mean and modal IRTs and standard deviation across the next two shaping procedures. Distributions 4 and 5 also show only slight changes. Distribution 6 shows IRTs for the second exposure to the FR 2 baseline condition. Comparing this data to the first exposure to FR 2 (distribution 1) indicates that mean and modal IRTs were less than those found on the first baseline condition. A comparison across distributions indicates a lack of systematic change in IRTs across the PRP shaping procedures.

The right panel of Figure 7 presents the PRP distributions. Distribution 1 has a unimodal shape. As the first IRT shaping procedure was applied, as shown in distribution 2, both standard deviation and mean and modal PRPs increased. Distribution 3 also shows an increased mean and modal PRP. Mean and modal PRPs and standard deviation both decreased in distribution 4. Distribution 5 shows an increase in mean and modal PRPs and an increase in standard deviation. This is contrary to the direction of shifting in
Figure 7. Relative frequency distributions of IRTs and PRPs as a function of the indirect effects of PRP and IRT shaping under FR 2 for Bird B6.
the other distributions, which shifted in the direction of the IRT contingency. Distribution 6 shows PRPs during the second exposure to FR 2. Mean PRP was higher on this second exposure. Comparing across all six distributions indicates an initial increasing trend in mean PRP, that then decreased, increased, and then decreased on second exposure to FR 2. Variability does not systematically change across the procedures.

Figure 8 presents the relative frequency distributions of IRTs and PRPs as a function of the indirect effects of PRP and IRT shaping under FR 2 for Bird BB. The left panel of Figure 8 shows the IRT distributions. Distribution 1 shows that the majority of IRTs fell within bin 7. Distributions 2 through 4 show only slight changes in mean IRT and standard deviation across the shaping procedures with modal IRT remaining stable. Distributions 5, 6, and 7 continue this trend of stable mean IRTs with slight changes in modal IRTs and standard deviations. Distribution 8 shows the second exposure to FR 2 baseline and indicates a similar mean IRT and distribution shape to the first exposure to FR 2. A comparison across all eight distributions indicates only slight changes across shaping procedures.

The right panel of Figure 8 presents the PRP distributions. Distribution 1 shows the majority of PRPs clustered in bins 2 through 5. Distribution 2 shows that when the FR 2 IRT > 0.35 s shaping procedure was applied, mean and modal PRPs and standard deviation increased.
Figure 8. Relative frequency distributions of IRTs and PRPs as a function of the indirect effects of PRP and IRT shaping under FR 2 for Bird BB.
Distribution 3 shows an increase in modal PRP but a decrease in mean PRP and standard deviation. Both mean and modal PRPs continued a decreasing trend, as shown in distribution 4, however, standard deviation increased. The changes in distributions 3 and 4 are in the opposite direction as would be expected from the contingency on IRTs. Distribution 5 shows PRPs from the FR 2 IRT < 1.33 s shaping procedure. Standard deviation and mean PRP both decreased as compared to the previous shaping procedure with modal PRP remaining stable. Mean PRP remains stable in distribution 6 and decreased in distribution 7. Standard deviation first increased and then decreased across distributions 6 and 7. Distribution 8 shows the majority of PRPs falling within bin 2. Mean and modal PRP is shorter under this second exposure to FR 2 as compared to the first FR 2 baseline condition. Comparing across all 8 distributions shows first an increasing and then a decreasing trend in mean PRP. No systematic change is apparent in standard deviations.

In summary, the indirect effects of the shaping contingencies differed between IRTs and PRPs. As a general rule, the length of the PRP changed in a direction consistent with the IRT shaping contingency, thus mirroring the changes in IRT as a primary effect. Thus, for example, if the contingency specified a reduction in IRT (a direct effect) the PRP was also reduced (indirect effect) compared to the previous shaping condition. In contrast, when the shaping contingency was applied to the PRP in the FR 2
schedule, directional changes in the IRTs were not parallel to PRP changes. Rather, compared to baseline, IRT distributions showed a lack of systematic change.

Perhaps these PRP indirect effects were due to an artifact of the IRT shaping procedures (both IRT > and IRT < procedures). If a bird did not space its responses on IRT > shaping or if it did not peck quickly enough on IRT < shaping the subject was exposed to a six-second blackout. The literature refers to postponement of a regularly scheduled reinforcer, as the omission effect (McMillan, 1971). The literature on the omission effect indicates that pauses after reinforcement omission (nonreinforced trials) should be shorter than pauses after reinforcement trials (McMillan, 1971; Trapp & Crossman, 1986).

Figure 9 presents mean pauses following reinforced and nonreinforced trials across IRT shaping procedures under FR 2 for each subject. The upper left panel shows data for Bird B2. The abscissa shows the FR 2 IRT shaping procedures and the ordinate shows mean pause in seconds. The striped bars show mean pauses following reinforced trials and the solid bars show mean pauses following nonreinforced (omission) trials.

Data for Bird B2 shows that mean PRP was longer after nonreinforced trials across both IRT shaping conditions. Data for Bird B7 is shown in the upper right panel. Again, the mean PRP was longer after nonreinforced trials as compared to reinforced trials for all four IRT shaping
Figure 9. Mean pauses following reinforced and nonreinforced trials across IRT shaping procedures under FR 2 for each subject.
procedures. Data for Bird B6 are shown in the lower left panel of Figure 9. The mean PRP was longer after nonreinforced trials on all four shaping procedures. Data for Bird BB are shown in the lower right panel. Mean PRP was longer after the nonreinforced trials as compared to the reinforced trials, with the exception of the IRT > 1.0 s shaping procedure. Under this procedure, the means after both reinforced and nonreinforced trials were identical. These data clearly contradict the omission literature.

A further question arises based on the findings presented in Figure 9. If there were clear differences between mean pauses after nonreinforced and reinforced trials in the IRT shaping procedures, perhaps this same result occurred in the PRP shaping procedures. Figure 10 presents mean pauses following reinforced and nonreinforced trials across PRP shaping procedures under FR 2 for each subject. The upper left panel shows data for Bird B2. The abscissa shows the FR 2 PRP shaping procedures and the ordinate shows the mean pause in seconds. The striped bars show mean pauses following reinforced trials and the solid bars show mean pauses following nonreinforced trials. The pause following nonreinforced trials was longer on six of eight PRP shaping procedures. The pause following reinforced trials was longer on the PRP > 1.90 s shaping procedure and on the PRP < 0.75 s shaping procedure. Data for Bird B7 are shown in the upper right panel. Note that data are not shown for the PRP < 2.90 s shaping procedure.
Figure 10. Mean pauses following reinforced and nonreinforced trials across PRP shaping procedures under FR 2 for each subject.
In this procedure all of the trials were reinforced, hence the inability to sort the data into reinforced and nonreinforced trials. Three of the five procedures had longer mean pauses following nonreinforced trials. Data for Bird B6 are shown in the lower left panel. Three of four procedures had longer mean pauses following nonreinforced trials. Data for Bird B8 are shown in the lower right panel of Figure 10. For all six PRP procedures, the mean pauses following nonreinforced trials were longer. The data presented in this figure support the data in Figure 9. There are, however, more instances in which the pauses after reinforced trials were longer as compared to Figure 9. Overall, however, the relationship of longer pauses after nonreinforced trials was upheld on the PRP shaping procedures.

Comparison of Nonreinforced Trials Across Conditions

A hypothesis proposed in this study was whether IRTs and PRPs are similar temporal units. If they are similar, it would be predicted that changes in the temporal units would occur at approximately the same rate as differential reinforcement was applied. In other words, it would take about the same number of trials to produce a change in each type of temporal unit. One method of determining if there was a difference in the rate of change between IRTs and PRPs is to compare the number of errors that each subject made in each shaping condition. Errors are nonreinforced trials
(i.e., reinforcement was not delivered due to a subject responding too soon, or waiting too long to respond). If there were a difference in number of errors when making a comparison across IRT and PRP shaping conditions, the conclusion could be drawn that one temporal unit was more easily shaped than the other. For example, if 100 errors were made on a particular PRP shaping procedure, and 50 errors were made on an IRT shaping procedure, the conclusion could be drawn that the PRP was the more difficult temporal unit to shape.

Tables 3 and 4 show mean errors across each shaping procedure for each subject. Table 3 presents errors for subjects in group 1 and Table 4 presents errors for subjects in group 2. Table 3 shows mean errors for each shaping procedure in the top half of the table and mean errors across the entire shaping conditions in the bottom half of the table. Asterisks indicate a procedure in which criterion two was met. Means in the top half of the table were calculated by dividing the total number of errors made in a procedure by the number of sessions in the procedure. Means in the bottom half of the table were calculated by dividing the total number of errors made in the condition by the number of sessions in the condition. The top half of Table 3 indicates a lack of a consistent error patterns across the different procedures for either subject. The bottom half of the table indicates that both subjects made more errors during the IRT shaping conditions.
Table 3

Mean Errors Across Each Shaping Procedure for Each Subject in Group One

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<td>FR 2 IRT &lt; 0.63 s</td>
<td>68.00</td>
</tr>
</tbody>
</table>

Mean Errors for the Entire Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean</th>
<th>Condition</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR 2 PRP</td>
<td>47.68</td>
<td>FR 2 PRP</td>
<td>65.34</td>
</tr>
<tr>
<td>FR 2 IRT</td>
<td>105.78</td>
<td>FR 2 IRT</td>
<td>72.53</td>
</tr>
</tbody>
</table>
Table 4

**Mean Errors Across Each Shaping Procedure for Each Subject in Group Two**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Mean</th>
<th>Procedure</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR 2 IRT &gt; 0.30 s</td>
<td>49.75</td>
<td>FR 2 IRT &gt; 0.35 s</td>
<td>22.00</td>
</tr>
<tr>
<td>FR 2 IRT &gt; 0.93 s</td>
<td>200.87*</td>
<td>FR 2 IRT &gt; 0.65 s</td>
<td>44.38</td>
</tr>
<tr>
<td>FR 2 IRT &lt; 0.93 s</td>
<td>4.00</td>
<td>FR 2 IRT &gt; 1.00 s</td>
<td>48.25*</td>
</tr>
<tr>
<td>FR 2 IRT &lt; 0.30 s</td>
<td>75.09</td>
<td>FR 2 IRT &lt; 1.00 s</td>
<td>19.50</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 1.45 s</td>
<td>67.01</td>
<td>FR 2 IRT &lt; 0.65 s</td>
<td>31.50</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 2.63 s</td>
<td>65.60</td>
<td>FR 2 IRT &lt; 0.35 s</td>
<td>327.64*</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 2.63 s</td>
<td>18.00</td>
<td>FR 2 PRP &gt; 0.70 s</td>
<td>30.14</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.45 s</td>
<td>42.67</td>
<td>FR 2 PRP &gt; 1.13 s</td>
<td>34.67</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 1.88 s</td>
<td>65.50</td>
<td>FR 2 PRP &lt; 1.88 s</td>
<td>15.00</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.13 s</td>
<td>19.50</td>
<td>FR 2 PRP &lt; 0.70 s</td>
<td>42.00</td>
</tr>
</tbody>
</table>

Mean Errors for the Entire Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean</th>
<th>Condition</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR 2 IRT</td>
<td>124.18</td>
<td>FR 2 IRT</td>
<td>161.43</td>
</tr>
<tr>
<td>FR 2 PRP</td>
<td>64.21</td>
<td>FR 2 PRP</td>
<td>37.33</td>
</tr>
</tbody>
</table>
Table 4 shows errors for subjects in group 2. The top half of the table indicates an increase in the number of errors as the temporal criteria were increased for both the IRT and PRP shaping procedures for both subjects. The only exception was on the FR 2 PRP > 1.45 s and FR 2 PRP > 2.63 s shaping procedures for Bird B6 where the error rates remained about the same. Error rate also increased as the temporal criteria were decreased on both the IRT and PRP shaping procedures for both subjects. The bottom half of the table indicates that both subjects made more errors during the IRT shaping conditions.

A test of statistical significance was conducted to determine if there was a statistically significant difference between errors made on the IRT or PRP conditions. A paired differences t-test was conducted. The results were found to be not significant, $T = -2.468$, $p=0.09$.

An additional analysis was conducted to determine if there was a difference between the percentage change of PRPs and IRTs. Percentage change of PRPs and IRTs were calculated by comparing baseline durations of PRPs or IRTs with the maximum duration change that was produced by PRP or IRT shaping. Table 5 shows percentage change in PRPs and IRTs as a function of PRP and IRT shaping for each subject in Experiment 1. The left half of the table shows percentage change for each subject on the PRP shaping condition while the right half of the table shows percentage change for the IRT shaping condition. The data indicate
Table 5

Percentage Change in PRPs and IRTs as a Function of PRP and IRT Shaping for Each Subject in Experiment 1

<table>
<thead>
<tr>
<th>Subject</th>
<th>PRP Shaping Percentage Change</th>
<th>Subject</th>
<th>IRT Shaping Percentage Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bird B2</td>
<td>300%</td>
<td>Bird B2</td>
<td>0%</td>
</tr>
<tr>
<td>Bird B7</td>
<td>228%</td>
<td>Bird B7</td>
<td>141%</td>
</tr>
<tr>
<td>Bird B6</td>
<td>141%</td>
<td>Bird B6</td>
<td>110%</td>
</tr>
<tr>
<td>Bird B8</td>
<td>470%</td>
<td>Bird B8</td>
<td>126%</td>
</tr>
</tbody>
</table>
that for all four subjects, percentage change was greater for the PRP shaping condition. A paired difference t-test indicated, however, that the difference between the two conditions was not statistically significant, $T = 2.604$, $p=0.08$.

In summary, a greater number of errors were made in the IRT shaping condition as compared to the PRP shaping condition for all subjects. In addition, percentage change was greater for the PRP shaping condition. However, neither difference was found to be statistically significant.
CHAPTER IV

EXPERIMENT 2: MANIPULATION OF PRP DURATIONS THROUGH THE USE OF DIFFERENTIAL REINFORCEMENT WITH A FIXED-RATIO ONE RESPONSE REQUIREMENT

Experiment 1 demonstrated that both PRPs and IRTs were susceptible to differential reinforcement. However, characteristics of the PRP shaping procedure used in Experiment 1 could have influenced the obtained results. In Experiment 1, an FR 2 schedule requirement was used. A basic premise proposed in this study was that intervening events should not occur between the occurrence of the response to be reinforced and the delivery of that reinforcement. This was not the case in the PRP shaping procedure. In this procedure reinforcement delivery was delayed until after the occurrence of an IRT. Perhaps the occurrence of this intervening IRT could have influenced the obtained results. Therefore, in Experiment 2 subjects were exposed to PRP shaping procedures that used schedules of both FR 1 and FR 2.

Method

Subjects

Two experimentally naive homing pigeons of undetermined sexes and ages served as subjects. Subjects were maintained as described in Experiment 1.
Apparatus

The apparatus was the same as described in Experiment 1.

Procedure

Initial training was the same as described in Experiment 1. On the day following initial training the subjects were started on the baseline condition.

Experimental design. To control for possible sequence effects, the experimental procedures were presented in a different order to each subject. Bird B1 was exposed to the following procedures: FR 2 baseline, FR 2 PRP > t, FR 2 PRP < t, FR 1 baseline, FR 1 PRP > t and FR 1 PRP < t. Bird B3 was exposed to FR 1 baseline, FR 1 PRP > t, FR 1 PRP < t, FR 2 baseline, FR 2 PRP > t and FR 2 PRP < t. Table 6 shows each procedure, order of presentation and number of sessions on each procedure for both subjects.

Baseline condition. Baseline consisted of exposing each subject to either an FR 1 or FR 2 schedule. Trials started with keylight and houselight onset. A reinforcement cycle of three seconds followed one (FR 1) or two (FR 2) pecks to the key. A three second ITI (all chamber lights extinguished) followed reinforcement delivery. Sessions terminated after 40 reinforcement deliveries. Subjects continued in the baseline condition until stable responding had developed. The stability criterion was the same as that defined in Experiment 1.

Shaping procedures. The FR 2 PRP > t and FR 2 PRP < t
Table 6

Each Procedure, Order of Presentation and Number of Sessions on Each Procedure for Each Subject in Experiment 2

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number of Sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bird B1</td>
<td>Bird B3</td>
</tr>
<tr>
<td>FR 2 Baseline</td>
<td>18</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 1.00 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 1.90 s</td>
<td>10</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 3.70 s</td>
<td>33</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 3.70 s</td>
<td>2</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.90 s</td>
<td>2</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.00 s</td>
<td>5</td>
</tr>
<tr>
<td>FR 1 Baseline</td>
<td>15</td>
</tr>
<tr>
<td>FR 1 PRP &gt; 1.00 s</td>
<td>3</td>
</tr>
<tr>
<td>FR 1 PRP &gt; 3.50 s</td>
<td>25</td>
</tr>
<tr>
<td>FR 1 PRP &lt; 3.50 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 1 PRP &lt; 1.00 s</td>
<td>4</td>
</tr>
<tr>
<td>FR 1 Baseline</td>
<td>31</td>
</tr>
<tr>
<td>FR 1 PRP &gt; 2.25 s</td>
<td>31</td>
</tr>
<tr>
<td>FR 1 PRP &gt; 3.63 s</td>
<td>20</td>
</tr>
<tr>
<td>FR 1 PRP &gt; 7.22 s</td>
<td>24</td>
</tr>
<tr>
<td>FR 1 PRP &lt; 7.22 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 1 PRP &lt; 3.63 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 1 PRP &lt; 2.25 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 1 PRP &lt; 0.67 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 0.67 s</td>
<td>3</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 1.25 s</td>
<td>4</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 1.70 s</td>
<td>6</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.70 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 0.67 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 3.10 s</td>
<td>7</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 3.10 s</td>
<td>2</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.70 s</td>
<td>3</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.25 s</td>
<td>1</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 0.67 s</td>
<td>1</td>
</tr>
</tbody>
</table>
shaping procedures were identical to the procedures described in Experiment 1. Calculation of temporal criteria and progression across the procedures were the same as described in Experiment 1. The FR 1 PRP shaping procedures were similar to the FR 2 PRP shaping procedures. The only difference between the two procedures was that food or blackout occurred after only one peck in the FR 1 PRP shaping procedures. Calculation of temporal criteria and progression across procedures were identical to the FR 2 PRP shaping procedures.

Results and Discussion

Both subjects completed initial training within two sessions. The dependent variables were mean PRP and IRT (when present) of the last session of each baseline and shaping procedure. Relative-frequency distributions of PRPs and IRTs (when present) for the same last sessions were also calculated. In addition, mean errors across procedures were also compared. Calculations of relative-frequency distributions and mean errors were the same as described in Experiment 1.

Direct Effects

Figure 11 presents the relative frequency distributions of PRPs under the FR 2 shaping procedures (left panel) and under the FR 1 shaping procedures (right panel) as a function of the direct effects of PRP shaping for Bird B1. The first distribution on the left shows PRPs in the FR 2
Figure 11. Relative frequency distributions of PRPs under the FR 2 shaping procedures and of PRPs under the FR 1 shaping procedures as a function of the direct effects of PRP shaping for Bird B1.
FR 2 CONDITIONS

BIRD B1

FR 1 CONDITIONS

BINS (.24999 s)
baseline condition. The majority of PRPs fell within bins 3, 4 and 5. Distribution 2 indicates that as the FR 2 PRP > 1.0 s shaping procedure was applied both mean and modal PRP increased. This trend continues across the next two shaping procedures. Changes in standard deviation were not systematic, however. Distribution 5 shows PRPs on the FR 2 PRP < 3.70 s shaping procedure. Mean and modal PRPs and standard deviation decreased as compared to the previous shaping procedure. Mean and modal PRPs continued to decrease as shown in distribution 6. Standard deviation also decreased. Mean and modal PRPs and standard deviation increased in the FR 2 PRP < 1.0 s shaping procedure as shown in distribution 7. The increased mean can be attributed to several large PRPs which fell within bin 40. Comparing across all 7 distributions indicates an orderly change in distributions in conjunction with the shaping requirements.

The right panel of Figure 11 presents the PRP distributions during the FR 1 procedures for Bird B1. Distribution 1 shows PRPs in the baseline condition. Most PRPs fell within bins 2, 3 and 4. Distributions 2 and 3 indicate that mean PRP increased. Modal PRP remained stable, as shown in distribution 2. Modal PRP increased in distribution 3. Standard deviations remained stable across these two shaping procedures. Distribution 4 shows a decrease in mean and modal PRs with the change in the shaping procedure to FR 1 PRP < t. The standard deviation increased, however, as compared to the previous shaping
procedure. Distribution 5 shows a further decreased mean PRP and standard deviation. Modal PRP remained stable, however. A comparison across all five distributions shows an orderly change in PRPs as the shaping contingencies were applied.

Figure 12 presents the relative frequency distributions of PRPs under the FR 2 shaping procedures (left panel) and under the FR 1 shaping procedures (right panel) as a function of the direct effects of PRP shaping for Bird B3. The first distribution on the left shows PRPs in the FR 2 baseline condition. The distribution has a unimodal shape. After application of the first shaping procedure, mean and modal PRPs increased. This trend continues across the next three shaping procedures. No systematic change in standard deviations were apparent, however. Distribution 6 shows PRPs in the FR 2 PRP < 3.10 s shaping procedure. The distribution shows a decreased mean and modal PRP. Distribution 7 shows a further decrease in modal PRP, however, mean PRP increased slightly as compared to the mean in distribution 6. Distribution 8 shows a stable modal PRP and a decreased mean PRP. Distribution 9 shows an increase in mean PRP with modal PRP remaining stable. Standard deviations did not show any systematic change across the four "less than" shaping procedures. A comparison across all 9 distributions shows that distributions shifted in accordance with the shaping procedures. Mean PRP increased
Figure 12. Relative frequency distributions of PRPs under the FR 2 shaping procedures and of PRPs under the FR 1 shaping procedures as a function of the direct effects of PRP shaping for Bird B3.
FR 2 CONDITIONS

BIRD B3

FR 1 CONDITIONS

PERCENTAGE OF PRPS

BINS (.24999 s)
across the PRP > t shaping procedures, but showed an erratic pattern across the PRP < t shaping procedures.

The right panel of Figure 12 presents the PRP distributions under the FR 1 procedures for Bird B3. PRPs are spread over a number of bins on the FR 1 baseline condition. Application of the first FR 1 shaping procedure resulted in increased mean and modal PRPs and standard deviation. The next two shaping procedures show a continued increasing trend in mean and modal PRPs; however, no systematic change in standard deviations are apparent. Distribution 5 shows PRPs on the FR 1 PRP < 7.22 s shaping procedure. Mean and modal PRPs decreased, whereas standard deviation increased as compared to the previous shaping procedure. Distribution 6 shows a further decreased mean PRP and a large decrease in standard deviation. Modal PRP remained stable. Distribution 7 shows a slight increased mean PRP. Modal PRP once again remained stable with the standard deviation decreasing. Comparing across all 7 distributions shows an orderly change in distributions as a function of the shaping contingencies, with the exception of distribution 7 which shows an increased mean PRP that is contrary to the shaping contingency in effect.

In summary, with the exception of the FR 1 PRP < 2.25 s shaping procedure for Bird B3, the PRP distributions for both the FR 1 and FR 2 shaping procedures showed a shift in accordance with the specified shaping contingencies. In addition, variability tended to increase across
distributions as the temporal values were increased and decreased as the temporal values were decreased. These findings directly support the results found for the PRP shaping procedures in Experiment 1.

Comparing between the FR 1 and FR 2 shaping conditions indicates no apparent difference between these conditions in producing changes in PRP lengths. Both conditions resulted in a change in PRP lengths as specified by the differential reinforcement contingencies. Therefore, it appears that the presence of an intervening IRT within the FR 2 PRP shaping procedure does not interfere with the effects of differential reinforcement.

Indirect Effects

Figures 11 and 12 demonstrated how PRPs changed as a function of the direct application of differential reinforcement. However, in the FR 2 shaping procedures an IRT also occurred. It is important to determine if this IRT changed, when free to vary, similarly to Experiment 1.

Figure 13 presents the relative frequency distributions of IRTs as a function of the indirect effects of PRP shaping under FR 2 for Bird B3 and Bird B1. IRT distributions for Bird B3 are shown in the left panel and distributions for Bird B1 are shown in the right panel. The first distribution of the left panel shows IRTs from the first baseline condition. Distribution 1 has a bimodal shape. The next four shaping procedures show that no systematic changes in mean or modal IRTs or standard deviations were
Figure 13. Relative frequency distributions of IRTs as a function of the indirect effects of PRP shaping under FR 2 for Bird B3 and Bird B1.
apparent. Distribution 6 shows IRTs on the FR 2 PRP < 3.10 s shaping procedure. Mean IRT and standard deviation decreased as compared to the previous shaping procedure; however, modal IRT remained stable. No apparent systematic changes are apparent in mean or modal IRTs or standard deviations across the remaining three shaping procedures. A comparison of all 9 distributions shows only minimal changes in mean and modal IRTs as a function of the PRP shaping procedures.

The right panel of Figure 13 presents IRT distributions for Bird Bl. Distribution 1 shows IRTs in the baseline condition. The distribution has a unimodal shape. The next three shaping procedures show no systematic changes in mean or modal IRTs or standard deviations. Distribution 5 shows IRTs on the FR 2 PRP < 3.70 s shaping procedure. Little change is apparent in this distribution and the remaining two distributions. Comparing across all 7 distributions indicates a lack of systematic change as a function of the shaping contingencies.

In summary, no systematic change in IRTs were apparent in either subject. This finding is consistent with the results found in Experiment 1.

Comparison of Nonreinforced Trials Across Conditions

Both the FR 1 and FR 2 shaping conditions produced a change in PRP lengths as a function of the direct effects of differential reinforcement. However, it is possible that
one of the conditions produced a more rapid change in PRPs than the other. Therefore, a comparison was made between errors emitted on both conditions to determine if there was a difference.

Table 7 shows mean errors across each shaping procedure for both subjects. The top half of the table shows mean errors for each shaping procedure and the bottom half shows mean errors between each shaping condition. Means were calculated as described in Experiment 1. Referring first to the top half of the table indicates that errors increased across both the $\text{PRP} > t$ and $\text{PRP} < t$ shaping procedures in both the FR 1 and FR 2 shaping procedures for Bird B1. Bird B3 shows fewer errors in the $\text{PRP} < t$ shaping procedures on both the FR 1 and FR 2 conditions. The bottom half of the table shows that Bird B1 had slightly fewer errors on the FR 1 shaping condition. Bird B3 had fewer errors on the FR 2 shaping condition.

In summary, no consistent pattern of errors was found between subjects. Therefore, it is not possible to conclude that there was a difference in the rate of shaping between conditions.
Table 7

Mean Errors Across Each Shaping Procedure for Each Subject in Experiment 2

<table>
<thead>
<tr>
<th>Bird B1</th>
<th>Bird B3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Procedure</strong></td>
<td><strong>Mean</strong></td>
</tr>
<tr>
<td>FR 2 PRP &gt; 1.00 s</td>
<td>14.00</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 1.90 s</td>
<td>60.50</td>
</tr>
<tr>
<td>FR 2 PRP &gt; 3.70 s</td>
<td>69.94</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 3.70 s</td>
<td>16.50</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.90 s</td>
<td>26.00</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.00 s</td>
<td>97.00</td>
</tr>
<tr>
<td>FR 1 PRP &gt; 1.00 s</td>
<td>36.33</td>
</tr>
<tr>
<td>FR 1 PRP &gt; 3.50 s</td>
<td>59.28</td>
</tr>
<tr>
<td>FR 1 PRP &lt; 3.50 s</td>
<td>15.00</td>
</tr>
<tr>
<td>FR 1 PRP &lt; 1.00 s</td>
<td>61.50</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 3.10 s</td>
<td>17.50</td>
</tr>
<tr>
<td>FR 2 PRP &lt; 1.70 s</td>
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</tr>
<tr>
<td>FR 2 PRP &lt; 0.67 s</td>
<td>1.00</td>
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</table>

Mean Errors for the Entire Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean</th>
<th>Condition</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR 2 PRP</td>
<td>65.36</td>
<td>FR 2 PRP</td>
<td>26.07</td>
</tr>
<tr>
<td>FR 1 PRP</td>
<td>56.12</td>
<td>FR 1 PRP</td>
<td>55.33</td>
</tr>
</tbody>
</table>
CHAPTER V
GENERAL DISCUSSION

The function of differential reinforcement in the control of temporal units has been extensively examined, particularly in research on schedules of reinforcement. However, in the majority of cases, the temporal units have been examined in complex circumstances. For example, Anger (1956) used a variable-interval five minute reinforcement schedule to increase IRT durations. Williams and Shull (1982) decreased PRP durations by delivering reinforcement after completion of a fixed-ratio 70 or 75 reinforcement schedule only if the initial PRP was shorter than a specified duration. In both of these studies, numerous responses occurred between the reinforced temporal unit and the delivery of the reinforcing stimulus. The present research examined the effects of differential reinforcement on PRPs and IRTs in a simple context. Only one PRP and/or IRT occurred before the delivery of differential reinforcement.

PRP Shaping

Experiments 1 and 2 demonstrated that PRP durations could be systematically shaped to increase or decrease through the use of differential reinforcement. These results are consistent with the data of DeCasper and Zeiler (1977) and Platt (1984) who demonstrated that PRPs could be increased and with Church and Carnathan (1963) and Williams
and Shull (1982) who showed that PRPs could be decreased. In addition, the present study demonstrated that differential reinforcement functioned in an identical fashion in shaping PRP durations in both increasing and decreasing directions. This finding directly contradicts that of Catania (1970). Catania used a discrete trial procedure in a simple context (i.e., FR 1 schedule) to both increase and decrease latencies to respond (PRPs). He concluded that different processes controlled the increasing and decreasing functions of these latencies because of the differences he found in changing the latencies in each direction. In the present study, no differences were apparent between increasing and decreasing PRP durations.

IRT Shaping

Experiment 1 also demonstrated that IRT durations could be systematically shaped through the use of differential reinforcement. These results are consistent with research that examined the effects of differential reinforcement on increasing IRT durations (e.g., Anger, 1956; Malott & Cumming, 1964; Platt, 1984; Richardson & Loughead, 1974; Staddon, 1965). In addition, the present results demonstrated that the IRT could be systematically shaped in both increasing and decreasing directions.

An alternative explanation of the results found on the IRT shaping condition is possible, however. What could have been shaped was a temporal unit composed of both the PRP and
IRT, rather than the IRT in isolation. Zeiler (1970) demonstrated that temporal units, composed of both PRPs and a fixed number of IRTs, were susceptible to differential reinforcement. In the present study, IRTs changed as a function of the differential reinforcement contingencies. In addition, PRPs also changed in accordance with the reinforcing contingencies imposed upon the IRTs. Therefore, it is impossible to rule out whether the IRT in isolation, or a unit composed of both the PRP and IRT, were shaped.

**Shaping Effects**

Several characteristics of the changes in the PRP and IRT durations could have been the result of effects of the shaping process itself. These effects are overcompensation, variability and the shaping criterion that was used.

**Overcompensation**

An interesting finding of the shaping procedures was that subjects tended to produce PRPs and IRTs that were consistently longer than what was necessary to produce reinforcement. This process was termed overcompensation. A close examination of the moment-to-moment changes that occurred within a particular shaping procedure suggests a possible explanation for the overcompensation. As a particular shaping procedure was applied, for example, a PRP > t shaping procedure, a class of PRPs that formerly was reinforced under the baseline condition was subsequently subjected to extinction, i.e., the six-second blackout.
According to Morse (1966), two behavioral effects occur as a result of extinction. First, the topography of the behavior that previously received reinforcement tends to occur in a more variable form. And second, extinction eventually results in the reduction or elimination of a previously reinforced class of behaviors. In the present study, changes in the delivery of reinforcement produced both of these behavioral effects. Longer PRPs were produced by the subjects and short PRPs were greatly reduced in frequency.

At the same time, differential reinforcement effects were operating. If a PRP that was too short to produce reinforcement occurred, it resulted in a six-second blackout. In turn, this delayed the delivery of reinforcement by six seconds plus the temporal requirement. Subjects were always reinforced for emitting long PRPs but not for emitting short ones. Therefore, to produce the maximum amount of reinforcement in the shortest period of time, subjects had to produce long PRPs. Since long PRPs were always followed by reinforcement, this reinforced the tendency to produce longer PRPs in the future. This same analysis can be applied to overcompensation found in the IRT shaping procedures.

**Variability**

As durations of both temporal units were increased, a concurrent increase in variability also tended to occur. As the temporal durations were decreased, variability also tended to decrease. Systematic changes in variability are
often found in research on temporal differentiation. For example, Catania (1970) showed an increase in variability of responding as temporal durations were increased on differential reinforcement of long latencies schedules. Richardson and Loughead (1974) found that variability increased as the temporal durations were increased on differential reinforcement of low rate schedules. Similar results are also found on other temporal differential reinforcement procedures that examined key-peck durations (Kuch, 1974; Zeiler, Davis & DeCasper, 1980) and times to complete fixed-ratios (DeCasper & Zeiler, 1977).

A possible explanation of increasing variability across a shaping condition could be that the subject received reinforcement for longer and longer PRPs, that in turn led to the additional production of longer PRPs. In other words, the subjects were reinforced for producing longer and longer PRPs, while on the other side of the continuum longer and longer PRPs were being subjected to extinction as the shaping criteria were gradually increased.

Shaping Criteria

The type of criteria used in the shaping procedures could have influenced the ability to change the temporal units. Subjects were not run to stability (e.g., five days with no upward or downward trend in the data) because it was hypothesized that requiring subjects to continue on a particular shaping procedure would result in a particular temporal unit becoming difficult to shape to a new duration.
In other words, an extensive history of reinforcing a particular class of IRTs or PRPs may have inhibited changes in these temporal lengths when a new class of responses was subjected to differential reinforcement.

The majority of temporal differentiation studies have run subjects to stability (e.g., Catania, 1970; DeCasper & Zeiler, 1977; Kuch, 1974; Malott & Cumming, 1964; Zeiler et al., 1980); whereas, in the present study, subjects were run only until a reduction in the number of errors (nonreinforced trials) made per session was achieved. Subjects were then immediately switched to a new shaping criterion in the subsequent session. A systematic examination of change criteria on temporal differentiation procedures has not been completed to date, but may be an important factor in the ease at which temporal units can be shaped.

**Susceptibility Issues**

A basic question asked in this research was if there was a difference in the susceptibility of IRTs and PRPs to differential reinforcing contingencies. A comparison of the number of errors made on each shaping condition addresses the susceptibility issue. Tables 3 and 4 indicate that IRTs are more difficult to shape than PRPs, however, this difference was not statistically significant. It does appear, however, that there is a suggestion of a difference between the susceptibility of IRTs and PRPs to differential
reinforcement. This would support the contention that they are different temporal units.

An additional finding was that errors tended to increase as temporal durations were increased. In addition, errors also tended to increase as the temporal durations were decreased. In part, this supports and contradicts the literature. Catania (1970) reviewed several temporal differential studies and concluded that as temporal durations were increased subjects tended to respond less efficiently (i.e., made more errors); and as temporal durations were decreased, subjects tended to respond more efficiently (i.e., made fewer errors). The present results support Catania's contention that errors increase as temporal durations are increased but contradicts the contention that errors decrease as temporal durations decrease. A close examination of the relative frequency distributions across several studies perhaps helps to explain this unusual finding. Referring back to the relative frequency distributions in Figure 2 indicates that a major shift occurs in both the IRT and PRP distributions as the temporal procedures are applied. The shift in the entire distribution is not usually found in other IRT and PRP shaping procedures. For example, Catania's data show that some shift to the right occurred as a function of the DRLL schedules, but not to the extent of the shift shown in Figure 2 in the present results. The same finding occurs in research on IRT shaping. For example, Malott and Cumming
show a shifting to the right in relative frequency distributions as a function of various DRL contingencies. However, close examination of their data indicates that very short IRTs still occur across the various DRL schedules used.

This discrepancy between the present findings and other temporal differentiation studies may explain why errors increased as the temporal criteria decreased. Short IRTs or PRPs were not occurring on a periodic basis during the PRP or IRT > temporal procedures. In other words, short PRPs and IRTs had been eliminated from the subjects' behavioral repertoires. Therefore, when the PRP or IRT < shaping procedures were applied, the shorter temporal lengths reoccurred through the shaping process in a similar fashion to the PRP and IRT > shaping procedures. In other temporal research these short IRTs and PRPs never were completely eliminated, resulting in efficient responding on shorter temporal criteria.

**Indirect Effects**

Several differing effects between PRPs and IRTs were evident when PRPs and IRTs were free to vary.

**Temporal Durations**

When PRPs were free to vary on the IRT shaping procedures they tended to increase as the IRTs increased and decreased as the IRTs decreased, even though differential reinforcement was delivered independent of the PRP lengths.
When IRTs were free to vary no systematic change was apparent across all the PRP shaping procedures. The difference in IRTs and PRPs when free to vary, supports the contention that different variables control each temporal unit.

Effects of Blackouts on PRPs

An interesting result of the present study was the differing pause following reinforcement and blackout. Pauses following nonreinforced trials were greater than pauses following reinforced trials regardless if the PRPs were free to vary or were the subject of differential reinforcement. This clearly contradicts the literature. When reinforcement is postponed, this is called reinforcement omission. The omission literature shows that PRPs following reinforcement are greater than PRPs following reinforcement omission (McMillan, 1971; Staddon & Innis, 1966, 1969; Trapp & Crossman, 1986). Staddon (1970), in a careful review of the omission literature states that the behavior that occurs immediately following reinforcement omission is an enhancement of the behavior that occurs following a normally scheduled reinforcement. So, for example, what occurs following omission on fixed-interval schedules is a short PRP and a greater response rate as compared to the PRP and response rate following reinforcement. Therefore, Staddon (1970) predicts that what would occur on a DRL schedule is a depressed PRP and response rate, because that is an enhancement of the
behavior that is being reinforced. What occurs therefore, is a longer PRP following nonreinforced trials, and is the finding in the present results.

**Comparison Between the FR 1 and FR 2 Conditions**

The FR 1 control condition was conducted for two reasons. First, it was conducted to determine if the addition of the extra response which created an IRT somehow interfered with the ability to shape the PRP. A basic criterion of the present research was to use a simple procedure so that extraneous variables were largely eliminated. On the FR 2 procedure, an IRT intervened between the response (that produced the PRP) and delivery of the reinforcing stimulus. The hypothesis was that the intervening IRT would possibly interfere with shaping the PRP. A comparison of the results from the FR 1 and FR 2 conditions indicates that there was no apparent difference between the susceptibility of either condition to differential reinforcement.

A second reason for conducting this control condition was to determine if FR size somehow affected the results. Crossman, Trapp, Bonem and Bonem (1985) demonstrated that as FR size was increased on small fixed-ratio schedules, the PRP decreased. The FR 1 control condition was also conducted to determine if the change in FR size would inhibit the ability of differential reinforcement to change
PRP durations. Once again, no apparent differences between the FR 1 and FR 2 conditions were noted.

**Implications For a Comprehensive Theory of Reinforcement**

Interresponse time reinforcement theory consists of determining if IRTs function as discriminative stimuli or if they are functional units that are susceptible to reinforcement as other operants are (Reynolds & McLeod, 1970). The present results support the latter hypothesis because it was demonstrated that IRTs are susceptible to reinforcing contingencies. In addition, it was demonstrated that PRPs also change as a function of differential reinforcement in a similar fashion to IRTs. However, it appears that PRPs are more susceptible to the reinforcing contingencies because it took fewer trials to produce change in the PRPs as compared to the IRTs.

A examination of the literature indicates that additional temporal units are susceptible to reinforcing contingencies. Response durations (Kuch, 1974; Platt et al., 1973; Platt, 1984; Zeiler et al., 1980) and work times (DeCasper & Zeiler, 1974, 1977; Zeiler, 1970, 1972) have been systematically changed using differential reinforcement. A question remains, however, whether a comprehensive temporal theory can be used to explain the manipulation of temporal operants.

Since response durations and work times were not the
focus of the present research, this task is difficult. However, the first step in developing a comprehensive theory is to determine if there are sufficient similarities between IRTs and PRPs. The one similarity that was evident when examining these two temporal operants was that they were both susceptible to differential reinforcement. This finding is significant in the present research because this is the first demonstration that uses an identical reinforcement paradigm to change the two temporal operants separately within a single subject.

However, several significant differences were apparent when a comparison was made between the two operants. First, each operant, as mentioned above, showed differing susceptibility to the reinforcement contingencies. And second, differences were apparent between the operants when they were free to vary. Post-reinforcement pauses tended to increase and decrease in the same direction as the IRTs that were being subjected to differential reinforcement. No systematic changes in IRTs were apparent as the PRPs were subjected to differential reinforcement. This would tend to support the contention that different variables controlled the PRP and IRT lengths when they were free to vary.

But why do the PRPs and IRTs seem to be differentially affected? The PRP is a no-keypeck interval that follows reinforcement and precedes the first response, two quite dissimilar events; one is a stimulus event and one is a
response event. The behavior that occurs in this interval is topographically different than the subsequent key pecking. It may consist of pecking at, or around the hopper, preening, etc. In other words, FR performance may actually be a two-component heterogeneous chain. The behavior that follows the PRP is more or less continuous key pecking (separated by IRTs) up to the moment of reinforcement and so, resembles a homogeneous chain of responses. Perhaps what the present experiment has demonstrated is that it is easier to influence the first member of a heterogeneous chain than the second member, which is in itself, a homogeneous chain. Whether differential reinforcement has its greatest effect on the behaviors that occur during the PRP because such behaviors are topographically distinctive, and perhaps less cohesive than the second member (key-pecking) of the chain or because the first member is temporally more distant from reinforcement is a subject worthy of further investigation, and an issue that must be addressed by any comprehensive theory of ratio (and probably interval) performance.
REFERENCES


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PAPERS


A preliminary analysis of the notion of an establishing

DRO for responding to the establishing stimulus and/or for not waiting. Paper presented at the Association of Behavior Analysis meeting, Nashville, 1984.

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