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Some determinants of the postreinforcement pause on temporally-defined schedules.

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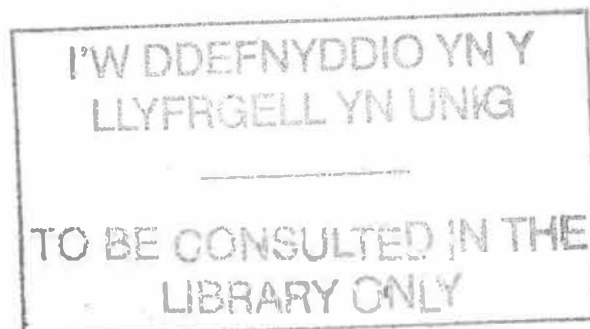

A THESIS SUBMITTED

BY

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Abstract

In Experiment 1 the response that terminated the postreinforce-
ment pauses occuring under a fixed-interval 60-sec schedule was re-
inforced, if the pause duration exceeded 30 sec. The percentage of
such pauses, rather than increasing, decreased. There were complex
effects on the discriminative control of the pause by the reinforcer
terminating the previous fixed-interval, depending on whether the
fixed-interval and the added reinforcer were the same or different.
In Experiments 2 and 3 each reinforcement initiated an alternative
fixed-interval interresponse-time-greater-than-t-sec schedule, the
schedule values being systematically varied. When the response
following a pause exceeding a given duration was reinforced, fewer
such pauses occurred than when they were not reinforced, i.e. on
the comparable simple fixed-interval schedule. There was no systematic
relationship between mean interreinforcement interval and duration of

the post-reinforcement pause. The pause duration initiated by rein-
forcement was directly related to the dependency controlling the
shortest pause at that time, regardless of changes in mean inter-
reinforcement interval.

In Chapter 7, the performance of rats was studied on different
values of the fixed-interval (FI) schedule. When postreinforcement
pause measures were related to schedule value it was found that the
pause was not a constant proportion of the schedule parameter but
rather the relationship was best described by a power function with
an exponent of less than one. Also, pigeons were trained on different
FI values under two conditions: (i) where the reinforcer was of 3 sec
duration and (ii) where the reinforcer duration was one-tenth of the
value of the interval. It was found that at the highest FI values,
longer pauses occurred following the longer reinforcer duration than
following the shorter reinforcer duration; power functions with
exponents less than one provided a good description of both types of
pause-interval relationship. Two further experiments investigated
reinforcement magnitude effects on FI when (i) only a single reinforcer
duration occurred in a session, and when (ii) different reinforcer
durations occurred within the same session. The postreinforcement
pause was directly related to the duration of the preceding reinforcer,
the effect being enhanced when different reinforcers occurred within
the same session and when the schedule parameter was increased. The
duration of the postreinforcement pause on FI schedules is shown to be
the product of a complex interaction between interval length and
reinforcement magnitude.

CONTENTS

CHAPTER ONE

INTRODUCTION

The early work of Thorndike (1898) on the escape of cats from
puzzle boxes led to the statement of a Law which came to dominate
the area of animal instrumental learning for half a century. In a
standard experiment, Thorndike studied the process by which a cat
learned to escape from a box by operating a latch. After initially
scrambling about the box, the cat eventually hit the release
mechanism, which allowed it to run out and obtain food. Using a
latency measure, Thorndike found that as trials progressed the time
to operate the latch from being placed in the box became shorter and
shorter. In Thorndike's view, the consequences of the cat's movement -
freedom and food - "stamped in" a connection between the stimuli of
the box and the particular movements that had been immediately followed
by release. Thorndike (1911) termed this principle the Law of Effect,

which states:

> Of several responses made to the same situation,
> those which are accompanied or closely followed
> by satisfaction to the animal will, other things
> being equal be more firmly connected with the
> same situation, so that, when it recurs, they
> will be more likely to recur; those which are
> accompanied or closely followed by discomfort to
> the animal, will, other things being equal, have
> their connections with that situation weakened,
> so that, when it recurs, they will be less likely
> to recur (1911, p.244).

Extending Thorndike's work, Skinner (1938; 1953; 1969) developed
his "Experimental Analysis of Behaviour", and his own apparatus (the
Skinner-box) as the major tool of investigation. A Skinner-box, or
'experimental space' as it later came to be termed, refers to any
apparatus in which a response (referred to as an 'operant' cf.
Skinner 1969) takes little time to occur and leaves the animal in
the same place ready to respond again; the adjective 'free' often
being used in conjunction with 'operant', emphasising that the subject
is 'free' to respond at any time the subject 'wishes' (Ferster 1953).
The response most often studied in rats and monkeys is a press on a
lever; with pigeons, it is usually a peck on a disc.

Instead of Thorndike's terms 'satisfiers' or 'annoyers', Skinner
adopted the term reinforcer, attempting to remove any mentalistic
connotations. A positive reinforcer is specified in relationship to
some particular behaviour emitted by an organism, and is defined as
"any stimulus which when made contingent upon a specified response
increases the future probability of that response" (Skinner 1953). In
the case where a stimulus which when made contingent upon a specified
response decreases the future probability of that response, then this

stimulus is termed a punisher (Azrin and Holz 1966); the term negative reinforcer is currently used to describe the increase in the probability of a response observed following the contingent removal of a stimulus. In this thesis reinforcement refers to positive reinforcement, unless otherwise stated.

Skinner and his associates also developed complex procedures whereby only some instances of the response were reinforced i.e. intermittent schedules of reinforcement (Skinner, 1938; Ferster and Skinner, 1957). These schedules, specified in terms of the minimum requirements necessary for the delivery of reinforcement, are usually defined with regard to either the minimum times between successive opportunities for a response to produce reinforcement (interval schedules) or the number of responses the organism has to emit to produce reinforcement (ratio schedules). These, as well as others and various combinations are described in detail by Ferster and Skinner (1957). Intermittent reinforcement procedures are especially interesting because they appear to be more representative of "real world" situations. The behaviour generated by exposing subjects to these procedures is also important because schedules produce, with training, their own particular patterns of behaviour, and this strengthens Skinner's (1969) suggestion that behaviour may be interpreted as a function of the environment in which it occurs, or, in other words, as a function of observable events in the physical world.

Dependent Variables

Whereas in the puzzle box situation latency was the dependent variable adopted, in the Skinner-box the major dependent variable

used became the frequency of occurrence of behaviour i.e. the mean
rate of responding over time (Skinner 1966; Ferster 1953).

Skinner (1950) states:

> It is no accident that rate of responding is
> successful as a datum, because it is particularly
> appropriate to the fundamental task of a science
> of behaviour, If we are to predict behaviour
> (and possibly to control it), we must deal with
> probabilities of response. The business of a
> science of behaviour is to evaluate this
> probability and explore the conditions that
> determine it... Rate of responding is not a
> "measure" of probability but it is the only
> appropriate datum in a formulation in these
> terms.

However, there are problems with the use of the overall rate
measure on free operant schedules of reinforcement. For instance, it
has often been noted that very different patterns of behaviour may
give rise to very similar overall rates and thus the patterning of
behaviour in time must be considered in addition to the gross output
of behaviour i.e. the overall rate (cf. Dukich and Lee, 1973; Lowe,
Davey and Harzem, 1974; Nevin 1973). It appears necessary therefore
to have a dependent variable which gives a much finer grain analysis
of behaviour than the overall rate measure. One such dependent variable
is the interresponse time (IRT) distribution, i.e. the distribution of
time lapses between responses. The IRT that is terminated by the
reinforced response is usually considered to be the reinforced IRT,
and although different versions of IRT theory differ in significant
details, they all attempt to show how the IRT distribution results
from the reinforcement of IRT's. In fact there is good evidence that
the IRT distribution on schedules depends upon which IRT's have been

reinforced (Alleman and Platt 1973; Anger 1956; 1973; Blough 1966; Malott and Cumming, 1964; Shimp 1969a, 1969b, 1974; Staddon 1968) and upon the rate of reinforcement for different IRT's (cf. Anger 1973).

There is, however, an important class of schedule effects that IRT theory has been unable to account for. On single response schedules subjects often cease responding for a while after each reinforcement; such pausing usually being of much longer duration than the time taken to consume the reinforcer. This postreinforcement pause is significant for several reasons. First, it is a very notice-able feature of behaviour on several schedules (cf. Ferster and Skinner 1957). Secondly, the duration of the pause is systematically related to schedule parameters (Felton and Lyon, 1966; Lowe and Harzem, 1977; Powell 1968). Thirdly, the postreinforcement pause is inter-esting because some interpretations of schedule effects have difficulty in accounting for it. For example, the pause data provide great difficulties for any theory based on the assumption that subjects maximise overall rates of reinforcement (cf. Logan and Ferraro 1970); on ratio schedules, pausing decreases the rate of reinforcement below the maximum possible (Felton and Lyon 1966; Priddle-Higson, Lowe and Harzem, 1976). Similarly, the presence of long postreinforcement pauses on ratio schedules is troublesome for IRT theory as such pauses are never reinforced on these schedules. More critical perhaps, are data showing that explicit manipulations of the reinforced IRT have little effect on pause (cf. Elsmore 1971(a); Dews, 1969; Killeen 1969; Morgan 1970; Farmer and Schoenfeld 1964; Shull 1971(a);

Staddon and Frank 1975; Zeiler, 1968). Thus, the postreinforcement pause appears to be an important feature of schedules both as a behavioural phenomenon, a theoretical problem, and a sensitive dependent variable.

Thesis Plan

The next chapter reviews the existing literature on the post-reinforcement pause and chapter three the literature on temporal discrimination. A series of experiments are reported which investigated the effects of different variables on the postreinforcement pause in temporal schedules. Though some doubts have been expressed regarding the usefulness of schedules of reinforcement (cf. Jenkins, 1970; Mackintosh, 1974), the present thesis follows the more optimistic suggestion of Nevin (1973) that:

> The processes determining steady state behaviour
> are assumed to be common to all aspects of learned
> behaviour. Systematic formulation of learning
> have not been notably successful in accounting for
> the data of acquisition and extinction, even though
> these phenomena are regarded as basic; learning
> theories have rarely been extended to deal with
> maintained performances at all... It is quite
> likely that maintained performances will prove
> simpler to systematize than the immensely complex
> aspects of behaviour in transition. If such a
> system can be achieved, the additional assumptions
> needed to incorporate acquisition and extinction
> may be fairly straightforward. (Nevin 1973 p.203).

It is hoped that this thesis, concerned with the postreinforcement pause in steady-state behaviour on free-operant schedules of rein-forcement, goes some way towards this systematization.

CHAPTER TWO

THE POSTREINFORCEMENT PAUSE: A SELECTIVE REVIEW

THE POSTREINFORCEMENT PAUSE AND SCHEDULE PERFORMANCE

The postreinforcement pause is, quite simply, the time from the delivery of reinforcement to the first response occurring after this event. Long postreinforcement pauses are a feature of many schedules, the major of which will be discussed here.

Fixed-Interval

On a Fixed-Interval (FI) schedule, the first response after a specified interval of time has elapsed is followed by reinforcement. The length of the interval may be timed from the previous reinforcement, or 'by the clock', that is from the end of the previous interval, regardless of when the reinforced response occurs. Fepster and Skinner (1957) point out that there is little difference between the two procedures.

As on other schedules, the postreinforcement pause does not appear the very first session that animals are placed on an FI schedule. Rather, more training is usually necessary before the postreinforcement pause appears. Early on in training animals usually respond immediately after reinforcement. Indeed, in the early sessions of FI training animals usually exhibit a 'respond-and-pause' pattern after reinforcement. Only after some training is this pattern reversed, with long postreinforcement pauses developing (cf. Cumming and Schoenfeld 1958).

The process can be speeded up however. Trapold, Carlson and Myers (1965) gave their animals non-contingent reinforcement for several sessions. These reinforcers were delivered at fixed-time periods. The animals were then placed on an FI schedule of the same duration as that of the earlier fixed time training. They found that these animals developed postreinforcement pauses more rapidly than animals who had been given no such training or animals who had received non-contingent pellets at variable time periods (cf. Trapold and Overmier 1972).

The duration of the postreinforcement pause, as on other schedules, is much larger than the time necessary to consume the reinforcer. For example, Skinner and Morse (1957) trained a rat on an FI 5-minute schedule. THey also placed a running wheel in the experimental space and they found that for a substantial period of time after each reinforcement, the lever was not pressed and running did not occur. Substantial running then took place for 2 or 3 minutes, which yielded to the behaviour of lever-pressing for the rest of the interval.

Very much longer postreinforcement pauses have been observed on FI schedules. Dews (1965) reported postreinforcement pauses of more than 1 hour on long FI durations of up to 24 hours.

SCHEDULE VALUE

The postreinforcement pause increases as a positive function of the FI value. Several investigators have reported that the post-reinforcement pause is a linear function of the FI duration and occupies a constant proportion of the FI irrespective of FI size (Dukich and Lee 1973; Sherman 1959; Shull 1971(b)).

MAGNITUDE OF REINFORCEMENT

It has been shown that on FI schedules the postreinforcement pause is a positive function of the preceding reinforcement magnitude (reinforcement magnitude being measured usually in terms of duration of access to grain, number of food pellets, or concentration or volume of a liquid reinforcer). Thus, the greater the magnitude of reinforcement on FI schedules the longer will be the duration of the postreinforcement pause which follows it (Jensen and Fallon 1973; Lowe, Davey and Harzem 1974; Staddon 1970a). However, the effects have been reported to occur only when different magnitudes are contrasted closely in time rather than when single magnitudes have been trained to stability (Jensen and Fallon 1973; Harzem, Lowe and Davey 1975a; Hatten and Shull 1972). In a series of experiments, Meltzer and Howerton (1973; 1975) have also found that where different magnitudes of reinforcement occurring at the end of the interval are signalled by different exteroceptive stimuli, response rates are higher in intervals leading to the higher reinforcement magnitudes.

OMISSION OF REINFORCEMENT

If reinforcement is omitted on FI schedules, then the duration
of the postreinforcement pause is smaller after omission than after
reinforcement (Kello 1972; Staddon and Innis 1966; 1969). Kello (1972)
exposed pigeons to an FI 2-minute schedule with the reinforcement cycle
consisting of extinction of the houselights and the key-light (black-
out) together with the illumination of the food magazine and access to
grain for a specified period. Once behaviour had stabilised, 50% of
the scheduled reinforcements were omitted and the non-reinforced
intervals ended in either (i) blackout and magazine light (ii) black-
out alone, or (iii) no stimulus change; each occurring with an equal
probability, the postreinforcement pause was longest following rein-
forcement, shorter following blackout and magazine light, shorter still
following blackout alone and shortest following the unsignalled
omission. The more that the omission stimulus approximated the
reinforcement cycle the longer the pause following that stimulus.

A factor influencing the omission effect is the sequence in which
reinforcement and omission occur. For instance, on an FI schedule
where N (non-reinforcement) and R (reinforcement) intervals are presented
in strict alternation, the omission effect is greater than if R and N
intervals occur randomly (Thomas 1970). Staddon (1972a) reports an
experiment in which intervals ended in N or R with equal probability,
but the conditional probability of an interval both beginning and
ending with N was 0.9 under one condition and 0.1 under another. The
pause was longer following N under the 0.9 condition than under the 0.1
condition, suggesting that the higher the probability that N is

followed by R the greater the omission effect (although in the experiment quoted the pause after N was always less than after R).

Another factor influencing the effect of the omission of reinforcement is the interval size; the omission effect is hardly observed at all at low interval values (Starr and Staddon 1974). Starr and Staddon explain these results by suggesting that at very short interval values there is little demand on the memory of the animal; if the animal can remember that a stimulus has just occurred which is separated in time from reinforcement then the animal will not respond. In longer intervals this memory task becomes more and more difficult and thus reinforcement, being a more 'memorable' event than blackout will control a longer pause.

DEPRIVATION

Collier (1962) looked at the effects of deprivation on FI schedules and found that the smaller the deprivation level of his animals the lower was the animal's overall response rate. Collier's data reveal that this lower overall response rate was due largely to longer postreinforcement pauses and lower running rates (i.e. the rate calculated after excluding postreinforcement pauses). Collier also looked at the momentary rate of responding and concluded that the lower response rates were due to more pausing between bouts of responding.

PUNISHMENT

Azrin and Holz (1961) punished responding on FI schedules. The postreinforcement pause was extended, though the authors report that responding was suppressed equally throughout the interval.

Fixed-Ratio

On Fixed Ratio (FR) schedules of reinforcement the last of a specified number of responses is followed by reinforcement, the number of responses being constant from one reinforcement to the next.

SCHEDULE VALUE

Postreinforcement pauses occur on FR schedules and are positively related to the ratio requirement of the schedule (Boren 1961; Felton and Lyon 1966; Powell 1968).

REINFORCEMENT MAXIMISATION

The optimum behaviour pattern for animals on FR schedules, from the point of view of maximisation of reinforcement rate, is to begin responding immediately after reinforcement. Yet, the occurrence of postreinforcement pauses on these schedules actually reduces the maximum overall rate of reinforcement. Logan and Ferraro (1970) state:

> As has been known all along, organisms generally behave in such a way as to maximize reward... the organism is viewed as monitoring its own output and being guided towards optimal behaviour by the relative incentive value of the alternative behaviours (p.119)

The postreinforcement pause on FR schedules is inconsistent with theories which suggest that organisms maximise reinforcement frequency. One possible explanation of this is that the animal is 'fatigued' after ratio completion and thus ceases responding. There is, however, experimental evidence which makes an explanation in terms of fatigue doubtful. When two different FR values are correlated with different exteroceptive stimuli and presented in random order within a session, the postreinforcement pause is appropriate to the forthcoming FR

signalled by the stimulus rather than the ratio just completed (Findley 1962; Griffiths and Thompson 1973).

INTER-REINFORCEMENT INTERVAL AND INTER-REINFORCEMENT RESPONSES

After training to stability on FR schedules delivery of reinforcement to animals on these schedules occurs at fairly regular time intervals. It has been argued that these temporal regularities of reinforcement delivery may exert effects on response-based schedules as an 'indirect' variable (cf. Zeiler 1977).

There is, in fact, evidence suggesting a positive relationship between postreinforcement pause duration and mean inter-reinforcement interval irrespective of the type of schedule involved. Berryman and Nevin (1962) trained rats on an FR schedule and four interlocking schedules. In their interlocking schedules the number of responses required for reinforcement decreased linearly as time passed since the last reinforcement, so that the subject could obtain reinforcement frequently by responding at a high rate, or could wait until t seconds had elapsed and receive reinforcement for a single response, or give any intermediate performance.

In all cases performance was characterised by a pause following reinforcement, which was a positive function of the time between reinforcements, regardless of whether reinforcements were programmed on a ratio schedule, an interval schedule or on an intermediate interlocking schedule (cf. Nevin 1973).

Similar effects have been reported by Killeen (1969) using pigeons yoked together in pairs. In a yoked procedure two experimental chambers

are connected so that the scheduling of reinforcements and/or stimuli for the subject in one chamber (the 'slave' subject) is controlled by the performance of the subject in the other chamber (the 'the'master' subject). In the Killeen (1969) study the 'master' birds were placed on different FR schedules, while the 'yoked' birds received reinforcements on an FI-like basis, although the intervals were not precisely constant. There appeared to be no difference between the postreinforcement pause on the FR schedules and the yoked control birds on the FI schedule.

Neuringer and Schneider (1968) exposed pigeons to FR and FI schedules, each response being followed by a blackout in order to suppress responding. On the FR schedule manipulating the duration of the blackout caused the time from the first response to reinforcement to change without affecting the number of inter-reinforcement responses; on the FI schedule the same procedure resulted in variations in the number of inter-reinforcement responses but not on the time of reinforcement from the first response. On the FR schedule, the postreinforcement pause duration increased with the increasing inter-reinforcement interval, whereas on the FI schedule, where the inter-reinforcement interval did not change, the postreinforcement pause remained constant.

Farmer and Schoenfeld (1964) devised a situation whereby a response was only reinforced if both a given FI had elapsed since the preceding reinforcement and the interval separating that response from the preceding response exceeded a specified time. The running rate was reduced greatly, but the duration of the postreinforcement pause was not affected. Other techniques which have produced the same results have been; requiring

only one response, anywhere in the interval, to produce a reinforce-
ment at the end of the interval (Shull 1970a) and changing the response
unit from a single response to a fixed number of responses (Shull,
Guilkey and Witty 1972).

These experiments lend strong support to the hypothesis that
temporal variables have a great influence on the postreinforcement pause
on response-based schedules. An experiment by Crossman, Heaps, Nunes
and Alferink (1974) however suggest that there may be an effect of
response number per se On FR schedules. They equated inter-reinforcement
intervals on small and large FR values by manipulating the duration of
blackout after each response. With the same mean inter-reinforcement
interval the postreinforcement pause was of greater duration on the
larger FR values than the smaller.

MAGNITUDE OF REINFORCEMENT

It has been observed that there is a positive relationship between
magnitude of reinforcement and the "postreinforcement pause following
that magnitude on FR schedules"(Lowe, Davey and Harzem 1974).

OMISSION OF REINFORCEMENT

If reinforcement is omitted on FR schedules, then the duration of
the postreinforcement pause is of smaller duration after omission than
after reinforcement (Henke 1973; McMillan 1971).

DEPRIVATION

Powell (1972) reports that the smaller the deprivation level of
pigeons on FR schedules the longer will be the duration of the post-
reinforcement pause.

PUNISHMENT

Azrin (1959) found that punishment of each response on FR
schedules greatly extended the duration of the postreinforcement
pause, although once responding had commenced the running rate was
little different from the non-punishment condition.

Inter-response-Time-Greater-Than-T-Seconds

On inter-response-time-greater-than-t-seconds (IRT>t) schedules, a
reinforcer is delivered immediately after a response, but only if a
specified interval has elapsed since the preceding response. This
schedule has also been termed differential-reinforcement-of-low-rate
(DRL), but following the suggestion of Zeiler (1977), the IRT>t
designation is used in this thesis. This schedule produces postrein-
forcement pauses which often approximate the duration of the schedule
value (Harzem 1969; Kramer and Rilling 1970).

Although the same contingencies are in operation after both reinforced
and non-reinforced responses on IRT>t schedules the typical finding is
that the pause following a reinforced response is longer than the pause
following a non-reinforced response (Carter and Bruno 1968a, b; Ferraro,
Schoenfeld and Snapper 1965). Harzem, Lowe and Davey (1975b)
developed a two-component IRT>t schedule in which a different IRT>t value
was in effect depending on whether or not a reinforced or non-reinforced
response had occurred, and they found that differential control ensued
i.e. the animals learned that different contingencies were in effect and
based their next IRT on the dependency in operation.

SCHEDULE VALUE

Whilst no study has yet shown the relationship between postrein-

forcement pause and schedule value, because the same contingencies are
in effect following both reinforced and non-reinforced responses this
relationship may be inferred from these studies which have related mean
IRT to schedule parameter. There is a positive relationship between
schedule value and mean IRT. However, unlike FI schedules in which the
postreinforcement pause has been reported to be a linear function of
schedule value and a constant proportion of the interval, the mean IRT
on IRT>t schedules is best described by a power function with an
exponent of less than one (Catania 1970).

Staddon (1972a, 1975a) has put forward a hypothesis - the 'natural
rate' hypothesis - to account for the different schedule value functions on
FI and IRT>t schedules. Specifically, he suggests that on IRT>t schedules,
where an organism is required to respond at a low rate in order to obtain
reinforcements, responding sometimes occurs rapidly, in 'bursts' (cf.
Harzem 1969; Kramer and Rilling 1970; Reynolds 1966) in order to bring
up the response rate to the natural level for the particular reinforce-
ment density. Conversely, because on FI schedules the animal responds at
a high rate in the latter half of the interval anyway, there is no need
to 'compensate'.

> One solution to the dilemma facing the pigeon
> on spaced-responding-schedules-that the more
> slowly he responds and the better he meets the
> spaced-responding requirement, the more rein-
> forcement he will receive and thus the more
> difficult it will be to maintain a low response
> rate - is to respond in bursts, with an
> appropriate spacing between bursts (Staddon 1972a p.227)

The evidence which Staddon (1972a; 1975a) uses to support his
hypothesis is the differing functions for postreinforcement pause on
FI and IRT>t schedules. Staddon (1975a) points out that this implies
a dependence on absolute time on IRT>t schedules that is not apparent
on FI schedules.

MAGNITUDE OF REINFORCEMENT

Increasing the magnitude of reinforcement on IRT>t schedules produces concomitant changes in the duration of the postreinforcement pause (Lowe, Davey and Harzem 1976), findings similar to those observed on FI and FR schedules.

OMISSION OF REINFORCEMENT

Although no direct studies of the omission effect have been reported, Caplan (1970) trained rats on IRT>8 sec and IRT>2 sec schedules, and then a proportion of reinforcements for 'correct' IRT's were omitted. The probability that a correct IRT would be reinforced varied from session to session, and ranged from 1.0 to 0.2; in place of reinforcement an auditory stimulus was presented. Response rate decreased - and efficiency increased - as   reinforcement probability increased. A similar effect has been reported by Davenport, Flaherty and Dyrud (1966) who employed a modified IRT>t procedure (cf. Mechner and Guevrekian 1962) with both monkeys and rats.

DEPRIVATION

Conrad, Sidman and Herrnstein (1958) reported that decreasing levels of deprivation brought about increases in the duration of postreinforcement pauses.

PUNISHMENT

Holz, Azrin and Ulrich (1963) found that punishment of responding on IRT>t schedules extended the pause after both reinforced and non-reinforced responses. These effects persisted despite any possible effect of the increased rate of reinforcement which the animals obtained.

Variable-Interval

On a variable-interval (VI) schedule the intervals between reinforce-
ments vary from one reinforcement to the next in a random, or nearly
random, manner (Ferster and Skinner 1957). A VI schedule is usually
specified in terms of the mean interval between reinforcements. How-
ever, the same mean interval may be produced by different distribution
of intervals. For example, an arithmetic VI schedule is derived from
a progression in which sucessive terms differ by an additive constant
(e.g. 10, 20, 30, 40 sec etc.) while in a geometric VI schedule the
intervals are derived from a progression in which successive terms differ
by a multiplicative constant (e.g. 5, 10, 20, 40 sec etc.). In another
type of VI schedule, random interval (RI), a recycling time interval is
specified at the end of which the first response will be reinforced with
a given probability. For example, on an RI 5-sec schedule, after each
5 sec period of time, the next response is reinforced with a constant
probability of, say, 0.1, thus probability of reinforcement does not
vary with the number of 5 sec periods since the last reinforcement. In
this schedule, the average interval between reinforcements is equal to
the recycling time interval divided by the probability of reinforcement;
the above example therefore would be an RI 50 sec schedule

i.e. $\quad \dfrac{T}{P} = \dfrac{5}{0.1}$

On VI schedules the postreinforcement pauses are usually relatively
short (cf. Nevin 1973; Hilgard and Bower 1966), yet postreinforcement
pauses of a duration far exceeding the time necessary to consume the
reinforcer have been observed on VI schedules (Harzem, Lowe and Priddle-
Higson 1978).

SCHEDULE VALUE

Lachter (1970), using an RI schedule in which p was held constant and T varied from 0 sec to 24 sec, found that the duration of the postreinforcement pause was an increasing function of the ratio $\frac{T}{p}$. Martin (1971) has shown a similar relationship between the pause after reinforcement and $\frac{T}{p}$ when T was held constant at 30 sec and p varied.

These studies suggest that the duration of the postreinforcement pause is a function of the mean inter-reinforcement interval on RI schedules. However, given the same inter-reinforcement interval the postreinforcement pause on VI schedules is of much smaller duration than that on IRT>t schedules (Richardson 1973). This finding suggests that there are factors over and above mean inter-reinforcement interval that affect the postreinforcement pause.

MAGNITUDE OF REINFORCEMENT

The postreinforcement pause has been found to be a positive function of the reinforcement magnitude on VI schedules (Campbell and Seiden 1974; Harzem, Lowe and Priddle-Higson 1978).

OMISSION OF REINFORCEMENT

The postreinforcement pause on VI schedules has been found to be of greater duration than the pause following a stimulus delivered in lieu of reinforcement (Harzem Lowe and Priddle-Higson 1978). Further, Thomas and Blackman (1974) found that when reinforcement omission was signalled (i.e. non-reinforced intervals were correlated with a change in key-light colour), the post-omission pause tended to be longer than when the reinforcement omission was unsignalled, although it was still

shorter than the postreinforcement pause. This latter finding is similar to effects observed on FI schedules where the probability of N is manipulated; the higher the probability of N following N, the longer the pause after N.

Variable-Ratio Schedules

On Variable-ratio (VR) schedules reinforcement occurs after a given number of responses, the number varying unpredictably from reinforcement to reinforcement. A VR schedule is usually identified in terms of the mean ratio i.e. the mean number of responses per reinforcement. Although pausing after reinforcement reduces overall rates of reinforcement such postreinforcement pauses do occur (Priddle-Higson, Lowe and Harzem 1976).

SCHEDULE VALUE

The postreinforcement pause is a positive function of the ratio requirement on VR schedules (Farmer and Schoenfeld 1967; Priddle-Higson, Lowe and Harzem 1976), findings similar to those reported earlier on FR schedules.

MAGNITUDE OF REINFORCEMENT

As on all the other schedules cosidered so far, the postreinforcement pause on VR schedules is a positive function of the reinforcement magnitude, the effect being enhanced on larger VR values (Priddle-Higson, Lowe and Harzem 1976).

OMISSION OF REINFORCEMENT

The postreinforcement pause on VR schedules is of greater duration than the pause after a stimulus delivered in lieu of reinforcement (Priddle-Higson Lowe and Harzem 1976).

Response-initiated Interval

On response-initiated interval schedules either a fixed-interval is initiated by the first response following reinforcement (tand FRIFI) or the first response starts a time period after which the reinforcer is delivered independently of any specific response at the end of that time period (tand FRIFT). As with ratio schedules pausing after reinforcement on these schedules reduces maximum overall rate of reinforcement and yet substantial postreinforcement pauses^occur on both tand FRIFI schedules (Lowe, Davey and Harzem 1974) and tand FRIFT schedules (Azzi, Fix, Keller and Rocha de Silva 1964; Dews 1960; Keller 1966; 1970). Having the first response produce a stimulus change does not appear to significantly change pause duration on response-initiated schedules (Azzi, Fix, Keller and Rocha de Silva 1964; Shull and Guilkey 1976).

SCHEDULE VALUE

On tand FRIFI schedules the postreinforcement pause increases with the duration of the interval initiated by the first response - the FI duration (Chung and Neuringer 1967; Shull 1970b). Shull (1978) has suggested that similar effects may occur on 'ordinary' FI schedules. He cites results (Shull 1971 b) which show correlations between length of time from the first response on FI schedules to reinforcement and the pause following that reinforcement.

MAGNITUDE OF REINFORCEMENT

There is a positive relationship between reinforcement magnitude and duration of the postreinforcement pause on tand FRIFI schedules (Lowe, Davey and Harzem 1974).

Fixed-Time Schedules

Perhaps the simplest conditioning procedure is one where food is delivered to an animal irrespective of the animal's behaviour i.e. with no response dependency. This in operant terms is a Fixed-Time (FT) schedule or in Pavlovian terms temporal conditioning. Pavlov (1927) first used the term temporal conditioning, hypothesising that the conditioned stimulus (CS) of time controlled behaviour.

In temporal conditioning the usual finding is that after some training the CR (conditioned response) e.g. salivation, occurs just before food delivery (Pavlov 1927). It is possible to view the time from food delivery to the onset of salivation as a postreinforcement pause.

In the typical FT schedule the animal is free to move about the experimental space in the time between food deliveries. Skinner (1948) used a procedure of this type and noted stereotyped behaviours, which he termed 'superstitions' e.g. the pigeon turned about the cage, performing pendulum motions of the head and body. Skinner offered an explanation of these behaviours by suggesting that reinforcement is always contingent on some behaviour, and no matter what that behaviour is, it would be 'strengthened' adventitiously by reinforcement. He noted that a 15 sec interval was much more effective in producing these 'superstitious' behaviours than a 1 min interval, suggesting that this was so because the sooner a second reinforcement appears the more likely it is that the second reinforced response will be similar to the first, and also that they will both have one of a few standard forms.

However, a later experiment examining the FT schedule by Staddon
and Simmelhag (1971) noted several different types of activity which
occurred in sequence. Some 'interim' activities (e.g. facing the window
wall, wing flapping) typically occurred early in the interval, whilst
other 'terminal' activities occurred late in the interval, such as
approaching the food-hopper and pecking. Staddon (1977) reports a
similar experiment with a rat that had opportunities for drinking and
running in a wheel. He reports that drinking and running, typical interim
activities, occurred early in the interval whilst feeder-area behaviours,
typical terminal activities, occurred late in the interval. These
results parallel those found in temporal conditioning i.e. food-related
behaviours occur late in the interval whereas other behaviours occur early
in the interval, and appear to produce similar Mathematical functions
(Killeen 1975). The postreinforcement pause could be viewed on FT
schedules as the time lapse between reinforcement and onset of these
food-related behaviours. The topography of interim behaviours appears
to be controlled primarily by the availability of behavioural alternative
and/or reinforcers unrelated to the terminal behaviour and reinforcer
(Staddon 1977). The topography of terminal behaviour, however, appears
to be determined largely by the nature of the terminal reinforcer and the
response requirements for that reinforcer (Elsmore 1971(a); Morgan 1970;
Shull, Guilkey and Witty 1972, 1975; Staddon and Frank 1975; Staddon
1977; Staddon and Simmelhag 1971).

INHIBITORY TEMPORAL CONTROL

Current explanations of the postreinforcement pause on different schedules have argued the notion of inhibitory stimulus control by the reinforcing stimulus. For example, the postreinforcement pause on FI schedules has frequently been accounted for in terms of the antecedent effects of the reinforcer (Dews 1970; Ferster and Skinner 1957; Kling and Schrier 1971; Nevin 1973; Staddon 1972). According to Ferster and Skinner (1957) the reinforcing stimulus serves as a discriminative stimulus on the FI schedule setting the occasion for a period of non-reinforcement.

Reid (1957) trained pigeons on a continuous reinforcement schedule (CRF) schedule. On such a schedule each response is reinforced. After this, Reid conducted a number of extinction sessions. When his animals had ceased to respond, he introduced a number of response-independent stimuli, such as a buzzer and a click, neither of which produced responding. After a food pellet was dropped in the food cup however, the pigeons began responding. Reid interpreted his results by suggesting that during the CRF sessions the reinforcer had developed discriminative stimulus properties, setting the occasion for the next response to be reinforced. He pointed out that:

> Reinforcing events are sources of stimulation, whatever else they may be, and therefore, in learning situations, they may be expected to gain some degree of stimulus control over the performance of the learned response (Reid 1957 p.202)

Ferster and Skinner (1957) have defined a discriminative stimulus as a stimulus in the presence of which a response is reinforced and in the absence of which it goes unreinforced. The implication seems to be that a stimulus must be present in order for it to exercise discriminative control, and, indeed, they suggested that residual stimuli e.g. particles of food in the mouth may still be present until late in an FI interval and thus produce a postreinforcement pause. This explanation appears doubtful however because, as already discussed, very long postreinforcement pauses of up to an hour have been observed on FI schedules and there is a positive relationship between the postreinforcement pause and FI value.

Hearst (1972) has defined an inhibitory stimulus as

> a multidimensional environmental event that as
> a result of conditioning develops the capacity
> to decrease performance below the level occurring
> when the stimulus is absent (p.67)

Conversely an excitatory stimulus has been defined as a stimulus that develops during conditioning the capacity to increase response strength above the level occurring when that stimulus is absent (cf. Hearst, Besley and Farthing 1970; Rilling 1977).

Staddon (1972(a)) has distinguished two forms of stimulus control, situational control and temporal control. On situational control Staddon (1972) says:

> operationally it implies that a controlling
> relationship can be demonstrated between a
> stimulus and the occurrence, but not the
> time of occurrence of behaviour; if the stimulus
> had not occurred, the behaviour might not have
> occurred or might have been less likely to
> occur, but the time of occurrence of each res-
> ponse instance cannot be predicted from any
> property of the stimuli (p.212-213).

This form of stimulus control is the type Ferster and Skinner (1957)
discuss (cf. Terrace 1966). On temporal control Staddon (1972a) says:

> If Event A (a stimulus) occurs at a certain
> point in time and can be shown to determine
> the time of occurrence of Event B (a response)
> which occurs at a later point in time, the
> label temporal control is proposed for the
> relationship - no matter what the Events A
> and B, no matter how long or short the time
> separating them, and no matter what other
> contextual dependencies may exist (p.213)

Thus, situational control may be said to set the occasion not for
a response but for the operation of temporal control.

On all the schedules previously considered, which produce signi-
ficant postreinforcement pauses, reinforcement is the stimulus with
the lowest relative proximity to further reinforcement. In effect
reinforcement signals a period of non-reinforcement and as such would
be expected to develop inhibitory temporal control. This signalling
role functions not only on time-based schedules but also on response-
based schedules. The requirement of a certain number of responses to
produce reinforcement means that there is a certain amount of time
required for the emission of those responses, and thus inhibitory
temporal control would be expected to develop.

The type of control exerted by the reinforcer on schedules of reinforcement
has been termed an "autocontingency" by Davis, Memmott and Hurwitz (1975).
They proposed a distinction between traditional contingencies (i.e. if
Event X - then Event Y) and a second class of relationships - autocontin-
gencies (if Event Y - then Event Y). As Staddon (1975(b)) has argued
however, the difference between autocontingencies and other temporal
contingencies appears to be only in the stimuli involved, not in the
contingency per se (cf. Harzem, Lowe and Davey 1975(b)).

Strong evidence for the inhibitory after-effects of the reinforcer on FI schedules comes from a study by Wilkie (1974) the idea of which was first suggested by Staddon (1969). In this study, pigeons responded on an FI schedule in the presence of a stimulus, which consisted of a line projected onto the response Key. Training sessions were followed by dimensional stimulus control test sessions during which the orientation of the line presented throughout the FI was varied. U-shaped (inhibitory) gradients of responding, with minimum responses occurring in the presence of the training stimulus were observed in the early part of the interval. Inverted U-shaped (excitatory) gradients of responding, with maximum responding occurring in the presence of the training stimulus, were observed in the terminal part of the FI. In one experimental condition reinforcement was occasionally omitted at the end of an interval and replaced by a brief blackout stimulus. It was found that when the preceding interval had ended in blackout, inhibitory gradients did not occur in the following interval. Wilkie's results suggest that inhibitory effects are present early in the interval and that these are dependent upon the occurrence of the preceding reinforcement. Several other lines of evidence suggest that the reinforcer develops inhibitory after-effects.

Non-Contingent Reinforcement

An experiment cosidered earlier (Reid 1957) showed that the reinforcer can develop excitatory temporal control whose effects are observed also when the reinforcer is delivered non-contingently.

Logan and Ferraro (1970) showed that the reinforcer could also exert inhibitory temporal control when delivered non-contingently. Rats

were trained on an FI 30 sec schedule. After training a 'free' rein-
forcer was delivered midway through the course of the 30 sec interval.
The effect of this reinforcer was to produce a pause and a subsequent
pattern of responding similar to that which normally occurred when the
animal was reinforced at the end of an interval. The authors concluded:

> The evidence is unequivocal: behaviour following
> free rewards is most analogous to that following
> earned rewards precisely as one would expect if
> a new interval were initiated by that reward
> even though it occurred at an unaccustomed time
> and independent of response (p.121).

Magnitude and Omission of Reinforcement

The experiments from many schedules discussed earlier showed that if
the reinforcer was replaced by another stimulus, the pause after this
stimulus was much smaller than that following reinforcement. Similarly,
the pause after a small reinforcement magnitude is smaller than the
pause after a longer reinforcement magnitude. Staddon (1974) has
interpreted these results in terms of memory. He suggests that rein-
forcement is more 'memorable' than non-reinforcement and that a larger
reinforcement is more memorable than a smaller one. As time progresses
it presumably is easier to remember the larger reinforcement than smaller
reinforcers or omission stimuli, and this 'memory' of a stimulus which
predicts reinforcement serves to increase the pause. However, one could
just as easily discuss these effects in terms of stimulus intensity;
the more intense the discriminative stimulus the better the control of
that stimulus. A study by Davey, Harzem and Lowe (1975) has shown that
changes in the magnitude of the reinforcer on an FI schedule are functionally
similar to changes in the intensity of a 'neutral' stimulus. Under one
test condition the intensity of the neutral stimulus was held constant

and the magnitude of the reinforcement varied, and under the other
test condition the magnitude of the reinforcer was held constant and the
intensity of the stimulus varied. The duration of the postreinforcement
pause was positively related to the magnitude of the reinforcer and
likewise the duration of the post-stimulus pause to the intensity of
the stimulus, although the durations of the postreinforcement pauses
were substantially longer than the durations of the post-stimulus
pauses. The authors state:

> The proposal in the present paper is that
> when the magnitude of a reinforcer is
> manipulated, not only its reinforcing
> property but also the control it has over
> the subsequent behaviour is affected.
> Changes in the magnitude of a reinforcer
> may affect its stimulus properties in the
> same way as any stimulus is affected by
> changes in its intensity (p.218).

One would expect that in schedules where the reinforcer is the
stimulus with the highest relative proximity to further reinforcement
(and thus exerting excitatory temporal control) then the omission effect
found in schedules where the reinforcer is the stimulus with the lowest
relative proximity to further reinforcement would not occur. Staddon
(1970b; 1972a, b) has studied the effect of reinforcement omission on
schedules which develop a negatively-accelerated response rate; i.e.
a 'respond-and-pause' pattern of behaviour. This schedule reinforced
Key-pecking on a VI basis for approximately 1 min after reinforcement;
for postreinforcement times longer than 1 min, reinforcement was
obtained only by withholding Key-pecking for at least 10 sec. This
procedure generated a negatively-accelerated response gradient, essentially
a mirror image of the FI scallap. When a 3 sec blackout was substituted

for 50% of the reinforcements, response rate after blackout was sub-
stantially lower than that following reinforcement, results which are the
reverse of those found with reinforcement omission on FI schedules.
Staddon (1970b) concludes:

> The effects of reinforcement omission in a
> situation depends entirely upon the after-
> effects of reinforcement in that situation.
> The effects on subsequent responding of a
> stimulus presented in lieu of reinforcement
> (i.e. non-reward) will be of the same kind
> as the effects of reinforcement, but generally
> of smaller magnitude (p.230).

Disinhibition

Pavlov (1927) first used the term 'inhibition of delay' to describe
the phenomenon where, if a period of time intervenes between the onset
of the CS and occurrence of the unconditioned stimulus (UCS) responding
was suppressed during this period. In many ways this procedure is
analogous to an FI schedule, reinforcement acting as a CS for further
reinforcement. Pavlov also found that if a novel stimulus is presented
early in the delay period, the CR re-appeared; he described this
effect as disinhibition.

When a novel stimulus is presented early in an FI schedule similar
effects occur. There is a reduction in the duration of the postreinforce-
ment pause and an increase in responding at that point in the interval
(Flanagan and Webb 1964; Heinrichs 1968; Singh and Wickens 1968). It is
also interesting to note that when a novel stimulus is presented later on
in the FI, the effect is to decrease the response rate (Heinrichs 1968).
This latter phenomenon is analogous to Pavlovian external inhibition i.e.
the unconditioned effects of a novel stimulus which serves to reduce the
occurrence of the CR (cf. Pavlov 1927). Davis and Iriye (1973) presented

a novel stimulus following both reinforced and non-reinforced responses
on IRT>t schedules. Rats were placed on IRT>t schedules of either 10,
20 or 30 sec with a tone, approximately 0.5 sec in duration, occasionally
presented midway in the IRT>t interval. The duration of IRT's were
found to be shorter following presentations of the tone and this effect
was strongest on the longer IRT>t values. Davis and Triye do not
report whether there was any difference in disinhibition effects in
intervals preceded by reinforced or non-reinforced responses. Brimer
(1972) has provided further evidence of disinhibitory effects of novel
stimuli. Using an IRT > 120 sec schedule and rats as subjects, he
presented a novel stimulus, a light which remained on for 3 mins, at
one of two fixed times, either 26 or 51 minutes after the start of a
session. The other 3 min test period was a "dummy" presentation i.e.
the light stimulus was not presented but response data were recorded
for comparison with data taken from the 3 mins during which the light
was on. Subjects had significantly higher response rates during the
stimulus than during dummy intervals.

Staddon (1974) suggests an explanation of the disinhibition effect
by postulating that one effect of a novel disinhibitory stimulus may be
to impair the animal's ability to recall the previous reinforcement which
exerts inhibitory control. The transience of the effect would be due to
the animal learning that the novel stimulus has the same contextual
significance as the previous stimulus, and thus ceases to attend to it.
According to this theory disinhibition should be more difficult to
demonstrate on FI schedules or in temporal conditioning than in Pavlovian
delay conditioning or operant priming schedules. The reason for this
assumption is that delay conditioning and operant priming schedules
involve a neutral stimulus as the signalling event whereas FI schedules

and temporal conditioning involve a highly salient stimulus i.e. food.
It would be expected that greater impaired recall of the neutral
stimulus would occur, it being presumably a less 'memorable' event
than food delivery. Staddon (1974) points out that partial or complete
failures to demonstrate disinhibition on FI schedules (Malone 1971;
Wallach and Ferraro 1969), contrasted with Pavlov's assertions of the
reliability of disinhibition effects, which Pavlov usually studied
using delay conditioning procedures, suggest that this may in fact be
the case.

Aversiveness of the Postreinforcement Period

Inhibitory stimulus control has often been reported to be aversive
to organisms (Terrace 1966; 1972). If the reinforcer acts as an
inhibitory stimulus in schedules of reinforcement it would be expected
that the period shortly after reinforcer delivery would be aversive.

The aversiveness of the postreinforcement period is suggested by
the finding that the FI stimulus (e.g. Key colour) at the start of the
interval acts as a negative reinforcer (Brown and Flory 1972) and as a
punishing stimulus (Dews 1970). Similarly, Appel (1963) using rats
on an FR schedule found that his animals would reliably press a second
lever in order to switch off the schedule completely. Azrin (1961) and
Thompson (1964; 1965) reported similar findings on FR schedules. These
'escape' responses (i.e. escape from the schedule) typically occur during
the postreinforcement pause.

Another kind of evidence suggesting that the postreinforcement period
is aversive comes from observations of behaviour during the postrein-

forcement pause. Typical behaviours observed have been polydipsia (Corfield-Sumner, Blackman and Stainer 1976; Falk 1961; 1966; Rosenblith 1970; Segal and Holloway 1963; Reynierse 1966; Stein 1964; Stricker and Adair 1966; Wuttke and Innis 1972) when a water bottle has been available, pica (Villareal 1967) where wood blocks have been available, wheel running (Levitsky and Collier 1968), and tail nibbling and other repetitive acts (Blackman 1968; Laties, Weiss, Clark and Reynolds 1965). However, in several experiments a target has been placed in the Skinner-box (either a live animal, usually of the same species, or a dummy) and it has been observed that in those schedules which produce postreinforcement pauses animals have been found to reliably attack these targets. Elicited aggression has frequently been reported to occur in response to aversive stimulation (Azrin and Holz 1966; Ulrich and Azrin 1962; Ulrich, Delaney, Kucera and Caborocco 1972; Hutchinson 1977), and schedule induced aggression typically occurs during the postreinforcement pause. In pigeons, attack rates are high in the postreinforcement pause period and are a decreasing function of time from the start of the postreinforcement period (Azrin, Hutchinson and Hake 1966; Knutson 1970). On IRT>t schedules both reinforced and non-reinforced responses signal a period of low reinforcement probability and attack rates have been found to occur throughout the IRT>t schedule (Knutson and Kleinknecht 1970). Squirrel monkeys on FR schedules show biting attacks during the postreinforcement pause or early in the ratio run (Hutchinson, Azrin and Hunt 1968) as do pigeons (Gentry 1968). Richards and Rilling (1972) report that when, on an FI schedule, pigeons were given the opportunity to attack a restrained target, their attack rates were highest during the early part of the interval. On VR and VI schedules aggression occurs, which is mainly confined to the postrein-

forcement period (Dove, Rashotte and Katz 1974; Webbe, De Weese and
Malagodi 1974).

It has been assumed throughout this discussion that animals can
discriminate time intervals signalled by the reinforcer, The next
chapter looks at evidence regarding such temporal discrimination.

CHAPTER THREE

TEMPORAL DISCRIMINATION : THE BACKGROUND

The literature reviewed in chapter two has indicated that
animals can learn to discriminate temporal properties of the environ-
ment, and thus come to pattern their behaviour in accordance with
these temporal properties. This thesis is concerned with behaviour on
temporally-defined schedules of reinforcement and this chapter therefore
looks specifically at experiments designed to investigate animals'
sensitivity to temporal variables. It is a fundamental point of this
thesis that animals are sensitive to the passage of time and thus
appropriate that evidence of such sensitivity should be discussed.

In an early report, Reynolds and Catania (1962) presented pigeons
with durations of between 3 and 30 seconds in 3-sec steps during which
a response key was dark. Following these dark-key durations the response
key was lit for 30 seconds. Responses on this key were then reinforced

intermittently depending on the duration of the prior dark-key stimulus. Thus, in one condition responses were reinforced only if the duration had been 3 seconds and in another if the duration had been 30 seconds. Under both conditions the pigeons showed the highest response rates at the duration associated with food and lower rates as the durations differed from the one associated with food. Reynolds and Catania observed much finer discriminations, for example, when food occurred only after the 30-sec interval three of the subjects showed higher response rates given the 30-sec interval than after a 27-sec interval.

Elsmore (1971b) scheduled either 9 or 21 sec timeout durations for pigeons. A variable-interval schedule was in effect following a particular timeout duration; no pecks were reinforced after the other timeout duration. In 40 sessions, differences in response rates following the two durations gradually developed. A maintained generalisation procedure was then imposed in which timeout durations were varied from 3 to 27 sec. The first 100 trials of the general-isation test showed unequivocal results; the prior differential training had established control of the animals' behaviour by the timeout duration associated with reinforcement. Thus the highest response rates occurred following the particular timeout duration associated with reinforcement in the differential training procedure.

Results similar to the above have been found by Perikel, Richelle and Maurissen (1974). They used two procedures: a one-key procedure and a two-key procedure. In the one-key procedure, pecks were rein-forced after presentations of a long-duration stimulus but not after

presentations of a short-duration stimulus. In the two-key procedure,
left-key pecks were reinforced after the long-duration stimulus and
right-key pecks after the short-duration stimulus. In both procedures,
the long-duration stimulus was 10 sec., and the short-duration stimulus
was increased from 1 to 8 sec in 1-sec steps. Discriminative control
developed with both procedures, but with greater accuracy in the two-
key procedure, in which a difference threshold was obtained at short-
duration values between 7 and 8 sec, or about 2.5 sec shorter than the
long-duration stimulus.

Reynolds (1966) modified the type of procedure so far discussed
to combine the temporal discrimination procedure with an IRT>t schedule.
Reynolds used a two-component procedure in which the key was red in one
component and blue in the other. Unlike other experiments in which the
first (dark) component was fixed by the experimenters, here the duration
of the first red-key component was under the control of the pigeons.
Two pecks were allowed and then the key was changed from red to blue.
If the time between red key pecks was 18 sec or greater, responses on
the blue key were intermittently reinforced; if, however, the red-key
time was less than 18 sec., responses were not reinforced. Reynolds
found that the time between red-key responses was typically less than
18 sec.; the IRT t data suggest little temporal discrimination since
most responses occurred too soon for reinforcement. However, the blue-
key response rates showed evidence of temporal discrimination like that
observed by Reynolds and Catania (1962). Blue-key response rates were
highest if the prior red-key interresponse time had been 18 sec. or
greater and lower if the prior interresponse time had been less than
18 sec.

Cowles and Finan (1941) used a discrete trial procedure with rats as subjects. The rats entered a Y-maze and were held in a compartment for either 10 or 30 sec. Following the delay, responses to either arm of the maze were reinforced depending on the duration of delay. A response to one arm was reinforced given a 10 sec. delay while a response to the second arm was reinforced given a 30 sec. delay. The experimenters found that the animals could be trained to go to the appropriate sides of the maze dependent on the duration of the delay.

Stubbs (1968) elaborated on the Cowles and Finan (1941) procedure. A three-key chamber was used: on the center key, pecks produced stimulus durations ranging from 1 sec. to 10 sec. (ten different durations being utilised). Following one of the durations, the center key went off and two side keys were turned on. A response to one side key was reinforced if the prior duration had been short and a response to the other if the duration had been long. Thus, if the stimulus duration had been 1 to 5 sec. one choice response was reinforced and if the duration had been 6 to 10 sec. the other response was reinforced. The results showed that the probability of a "long" response increased as an ogival function of stimulus duration. Similar results have been obtained with rats (Church, Getty, and Lerner 1976) and monkeys (Catania, 1970; Elsmore, 1972).

Whilst the above experiments show that animals can accurately discriminate stimulus durations and waiting time, Rilling (1967) trained pigeons to discriminate different FI schedules. One of two FI schedules was arranged on a center key. The response that completed an FI turned off the center key and turned on two side keys. Responses on the side keys were reinforced depending on whether the short or long

interval had been arranged.. Rilling obtained results similar to those
obtained under simple duration tasks. Animals responded on the
appropriate side-key depending on which FI duration had just occurred.

It appears that the stimulus conditions used as 'time-markers'
in temporal discrimination experiments exert important effects, in-
fluencing the formation of animal's temporal discriminations.
Stubbs, Vautin, Reid and Delehanty (1978) trained pigeons under an
FI schedule in which half of the intervals randomly ended with food
and the other half with a brief stimulus; in one condition a 0.5 sec.
stimulus and in another a 2.5 sec. stimulus.   Intermittently, the FI
schedule was interrupted by a choice situation: the FI stimulus went
off either 20 sec. or 100 sec. into an interval and two side-keys
were lit; one response was reinforced if the interval was interrupted
after 20 sec. and the second reinforced if the interval was interrupted
after 100 sec. The choice situation interrupted intervals that began
with food and those that began with a stimulus. Thus temporal discrimin-
ation performance could be assessed separately for durations (fixed
intervals) that began with different events. The experimenters found
that accuracy was high when either food or the salient, 2.5 sec.
stimulus began an interval but that accuracy was at a near chance
level when the less salient, 0.5 sec. stimulus began an interval.

Nelson (1974) combined features of the Reynolds (1966) study and
that of Rilling (1967). In the Nelson (1974) study pigeons emitted a
series of responses on the center key. Each response was recorded
with respect to the time between it and the prior response (inter-

response time). Eventually a response turned off the centre-key
stimulus and turned on two side-key stimuli; this change took place
only following certain responses, those with a 'Short' interresponse
time on some trials and a 'long' interresponse time on other trials.
A response on one side key was reinforced if the short interresponse
time had just occurred while a response to the alternate side key was
reinforced if the long interresponse time had just occurred. Across
conditions the long interresponse time class was the same, 5-7 sec.;
the short interresponse time was varied. Nelson found that all four
pigeons could discriminate responses with different interresponse times.
Accuracy of discrimination depended on the difference in time between
the short and long interresponse times, with accuracy approaching a
chance level as the two interresponse times approached each other.
Nelson's procedure extends temporal psychophysical research by having
the duration depend on a response, not the onset of some external
stimulus.

The examples quoted indicate that animals are quite sensitive to
temporal differences. Indeed, they demonstrate that animals can
differentially respond to duration differences of one part in five
(Nelson 1974) and one part in ten (Reynolds and Catania 1962). These
studies indicate that duration, like frequency, intensity, or spatial
extent is a discriminable property of stimuli. As Catania (1970 put it:

> Duration is a fundamental property of behaviour
> and the environment. Some of its properties
> are unique: it is irreversible; it can only
> change continuously; and it involves no
> obvious receptor. These properties create
> special problems in the design of experiments
> on temporal discrimination. They do not imply,
> however, that temporal discriminations must be
> dealt with in terms other than those used for

discriminations along other continua. It can
be argued that duration is given only by pro-
gressions of physical events, such as the move-
ment of the hands across the face of a clock or
recurring physiological processes within an
organism, and therefore that the study of
temporal discrimination must be reduced to the
study of sequences of behavioural or physiological
events. Such events, however, take place in
time; they are not in themselves time. They
allow time to be measured, but they do not
define it. Above all, to the extent that the
appeal to progressions of events is valid, it
does not preclude the direct parametric study
of temporal discriminations. The parametric
data are primary, for nothing can be said about
the mechanism of temporal discrimination until
the parametric characteristics of temporal
discriminations are known. Duration is a
property of the reinforcing environment and a
property of behaviour. Before we speak of
time in other ways, we should speak of it in
terms of the functional correspondences between
temporal properties of the environment and
temporal properties of behaviour. (p.38).

Catania (1970) treated IRT>t schedules as scaling procedures
that related temporal properties of responding to temporal properties
of the reinforcing environment i.e. he changed the IRT>t schedule
value and observed the effects on animals' IRT's. He analysed also
data from Malott and Cumming (1964) and Staddon (1965). Generally,
his findings were that the temporal spacing of responses over-
estimated the schedule value at short durations and underestimated
it at long durations. The indifference interval, the intermediate
duration at which neither overestimation nor underestimation occurred,
was about 10 secs.

The data were thus reasonably described as power functions of
the form:

$$T = kt^n$$

where T is the response measure and t the schedule value. K is a constant that depends on the units of measurement, and n is a constant that determines the slope of the function on logarithmic co-ordinates. Catania's data gave the function:

$T = 1.6t^{0.8}$, thus giving an indifference interval of about 10 seconds.

Power functions with exponents less than one have also been found in situations where response duration is differentially rein-forced (Ferraro and Grilly 1970; Kuch 1974; Platt, Kuch and Bitgood 1973); where ratio duration, postreinforcement pause and run time are differentially reinforced on FR schedules (Decasper and Zeiler, 1974; 1977). Similar functions also describe the relationship between inter-changeover time and changeover delay on a number of concurrent schedules (Stubbs, Pliskoff and Reid, 1977). One study which has not found exponents of less than one is that of Richardson and Loughead (1974) who studied high values (1 minute to 45 minutes) of the IRT>t schedule using rats and pigeons. Whereas, with rats, mean parameter values were $\hat{K} = 2.42$ and $\hat{n} = 0.84$, the mean values with pigeons were $\hat{K} = 0.15$ and n = 1.08, findings which contradict the frequent observation that IRT>t efficiency decreases with schedule value (cf. Harzem, 1969; Kramer and Rilling 1970). However, Platt (1978) analysed data from a study by Richardson (1973) which recorded Pigeons' key-pecking under approximately the same conditions as employed by Richardson and Loughead (1974), and found that mean IRT's, estimated from response rate plots, ranged from 3 to 12 seconds, all above the 2.79 seconds predicted by the Richardson and Loughead (1974) function. The Richardson and Loughead (1974) pigeon data therefore are rather anomalous.

These power functions are important because they conform to

the psychophysical law (Stevens 1957) which well describes data

from many different stimulus modalities. Further, it is the function

obtained from experiments investigating human psychophysical

judgments (cf. Catania 1970; Eisler 1976; Stubbs, 1978). Catania

(1970) reviewed several experiments in which human subjects had as

their task the estimation of time intervals. His results were directly

comparable to the results involving differential reinforcement of long

lateries in his own experiment. The human subject overestimated short

intervals and underestimated long intervals. Eisler (1976) in

summarising the results of many years of research on human temporal

judgments came to the same conclusion. Eisler reports that the mean

exponent of the power-functions was 0.9.

Catania (1970) drew a direct comparison between experiments with

humans involving the judgment of time intervals and animal's performance

on temporal reinforcement schedules:

> In the animal performance, the population of
> reinforced and unreinforced latencies may serve
> some of the same functions as instructions in
> an experiment with human subjects. The point
> is illustrated by selected data from experiments
> on psychophysical judgments of duration (p.31).

Thus, the evidence suggests that i) temporal discriminations can be

compared realistically to discriminations along other continua and

ii) that such discriminations may play a large role in temporally-

defined schedules of reinforcement. For example, Mackintosh (1974)

states:

> On an FI schedule, the subject learns that the
> occurrence of reinforcement signals that no
> reinforcement will be available for x sec. and
> therefore stops responding. As time passes, the

> subject finds it more difficult to discriminate
> between x sec and the time that has actually
> elapsed since the last reinforcement, and
> responding increases steadily. The postrein-
> forcement pause, therefore, is due to a tem-
> poral discrimination, and the initiation of
> a steadily increasing rate of responding is
> due to a breakdown in the temporal discrimin-
> ation. (p.170)

However, the literature pertaining to the relationship between postreinforcement pause and FI schedule value suggests that this relationship is not of the type found in other situations with strong temporal requirements. Rather than a power function with an exponent of less than one, the finding typically reported has been a linear relationship where the pause is a constant proportion of FI value (cf. Dukichand Lee 1973; Sherman 1959; Shull 1971(b)). If the postreinforcement pause on FI schedules is due to a temporal dis-crimination (cf. Mackintosh 1974) it would have been expected that a power function described the postreinforcement pause - interval size relationship (see Catania 1970). In a modified version of the FI schedule, the cyclic interval schedule, Innis and Staddon (1971) found however that power functions with exponents of less than one described the relationship between postreinforcement pause and schedule value. In cyclic interval schedules, a fixed sequence of different inter-reinforcement intervals (in ascending or descending order) is presented in each experimental session unlikethe studies cited earlier which reported a linear relationship. It may be that this procedural difference resulted in the differing types of functions obtained. Innis and Staddon were led to the conclusion that the fractional exponent was due to some extra limitation on temporal control in cyclic schedules.

Gibbon (1977) and Platt (1978) have proposed an explanation for
the apparent discrepancy between the power functions of many temporal
differentiation schedules and the linear relationship reported on FI
schedules. They point out that studies which have reported power
functions have related responding to schedule value (cf. Catania 1970;
Platt, Kuch and Bitgood 1973). However, in these studies there is a
difference between schedule value and the mean reinforced duration.
Presumably, for instance, on these studies, especially at lower schedule
values, the mean reinforced duration is longer than the minimum rein-
forced duration i.e. the schedule value. Thus, in these studies there
is the problem of what actually is the stimulus duration of which the
animal's response is presumed to be a psychophysical judgment. Platt
and Gibbon have suggested that it is the mean reinforced duration which
is the stimulus duration that comes to exert control over responding
rather than the minimum duration (the schedule value). Gibbon (1977)
points out that when responding is related to the mean duration of
reinforced times the power function of Platt, Kuch and Bitgood (1973)
approaches linearity. This analysis fares less well with the data of
Catania (1970). Gibbon (1977) and Platt (1978) therefore have suggested
that linear relationships may be found on all temporal schedules.
While this explanation deals with the difference
in functions between FI schedules and other temporal schedules (on
an FI schedule the mean reinforced duration is identical with the
schedule value) there still remains the discrepancy with the data from
human psychophysical judgments which report power functions with
fractional exponents (cf. Eisler 1975; 1976).

Further, whilst studies have been reviewed in Chapter two which
suggest that interreinforcement interval is an important variable
(cf. Nevin 1973) the question still remains whether it is the minimum
interreinforcement interval of a particular schedule or the mean
interreinforcement interval which is important. An experiment by
Logan (1967) suggests that minimum interreinforcement interval may
be the crucial variable on IRT>t schedules. He modified the customary
IRT>t schedule in which a rat is rewarded only if he waits for a period
of time between bar-presses; in this case the period varied unpredict-
ably between two equally likely values, each of which, once programmed,
remained in force until satisfied. The animal's postreinforcement pause
was appropriate to the smaller of the two IRT>t values rather than an
average of the two. This experiment casts doubt on Gibbon's (1977)
and Platt's (1978) suggestion that pause measures should be related to
mean reinforced durations if one wishes to produce a true psychophysical
scaling procedure for animals. However, it supports the practice of
Catania (1970) who considered schedule value to be the stimulus duration
of which the animal's response was considered to be a psychophysical
judgment. If this is the case, the anomaly of the FI schedule still
remains.

CHAPTER FOUR

EXPERIMENTAL METHOD

The following is a description of the subjects, apparatus and general procedure used in the experiments to be reported.

SUBJECTS

The subjects were either male hooded rats, purchased from Animal Suppliers (London) Ltd., or mixed breed pigeons purchased from Abbot Brothers (Norfolk) Ltd. All the animals were housed individually with ad libitum access to water and also, in the case of the pigeons, to grit. A 12 hour day/night cycle was in effect at all times with the 'day' beginning at 7.00 a.m. and ending at 8.00 p.m. The ambient temperature of the animal house was kept at approximately 20°C.

All animals were weighed daily at approximately the same time.
Throughout all the experiments each animal's weight was held at 80%
of it's mean weight over the final 5 days of the free-feeding conditions.
This level of deprivation was maintained by feeding varying amounts of
food each day. All animals were fed approximately 1 hour after each
experimental session.

APPARATUS

Standard Lehigh Valley Boxes were used in all experiments, the
model numbers being specified for each experiment. All experiments
were controlled by, and the data analysed on a DATA GENERAL NOVA 1200
computer. Responses and reinforcements were also recorded on Gerbrands
cumulative recorders. Each box was housed in a sound attenuating
cubicle, with an exhaust fan mounted at the back, producing an ambient
noise level of $60^{\pm}$ 2dB. All other apparatus details are given in the
actual experiment description.

GENERAL PROCEDURE

The rats were trained to press the lever by the method of
successive approximations (Ferster and Skinner, 1957), whilst the
pigeons were auto-shaped (Brown and Jenkins, 1968). The criteria of
stability are specified in the Method section of each particular
experiment. Each session commenced when the first reinforcer was
delivered, and lasted until the experimenter stopped the computer's
experimental control programme.

The data was then analysed on a separate analysis programme,
and read out onto a line-printer. A separate computer programme was
used to calculate the regression lines and the coefficients of

determination for power functions. This latter programme is on the
main computer at U.C.N.W. Bangor and is the Stat Pack V4 of Western
Michigan University. The computer programme used to calculate the
equation constants and coefficients of determination for the rectangular
hyperbolae is on the Manchester University computer and is an iterative
procedure developed by Paul Bevan (cf. Bradshaw, Szabadi and Bevan 1976).

The experimental designs used in the experiments are based on
single subject methodology as used extensively by psychologists working
in the tradition of the 'Experimental Analysis of Behaviour' (cf.
Skinner 1969), i.e. an emphasis on individual subjects being used as
their own controls. In the experiments to be reported a minimum of
four animals were used in each experiment. It has been argued that
when four subjects are used in a single-subject design and consistent
results are obtained with all four then it may be considered that
three replications have been performed of the original 'experiment'
(Sidman 1960).

In the experiments to be reported data are shown from each of
the animals in the experiment; discussions and illustrations of means
are only undertaken after the discussion and illustration of each
individual animal's results. As Boakes and Halliday (1970) noted:

> An average result does not always represent a
> typical result. For example, a learning curve
> may show a smooth and steady increase in the
> number of correct trials for the average rat and
> thus suggest that learning is a steady, incremental
> process; in contrast the results from a single
> rat usually displays a number of sequential
> patterns which indicate that learning is a much
> more complex process than one would infer from
> the averaged data. A number of other examples

       in very different areas could equally well
be cited, since this is a common problem
whose importance has been recognised by many
psychologists besides Skinner. It is crucial
here because in order to discover whether
averaged results are representative one needs
to know in some detail about the behaviour of
individuals and any sloppiness in the experi-
mental conditions will greatly impoverish this
knowledge (p. 363).

Finally, the 'postreinforcement pause' refers, in this thesis, to

the time lapse between delivery of the reinforcer and the first

response to occur after this event.

CHAPTER FIVE

REINFORCEMENT OF RESPONSES TERMINATING POSTREINFORCEMENT PAUSES
ON FIXED-INTERVAL SCHEDULES

On a fixed-interval (FI) schedule the first response is rein-
forced either after a stated minimum interval has elapsed since
previous reinforcement, or, in the case of FI schedules timed 'by
the clock', in each of successive equal intervals. This schedule
has attracted considerable research interest, mainly because FI
performance is thought to provide evidence about temporal discrimin-
ation, that is, the ways in which an organism's behaviour adjusts to
the temporal contingencies operating in a given situation. Typically,
performance in a single interval of the FI schedule begins with a
pause (the postreinforcement pause) and ends in a steady and rather high
response rate. Two aspects of this pattern have been studied in some
detail: the transition from the pause to the high response rate, and

determination of the duration of the post-reinforcement pause.
Responding following the postreinforcement pause is usually accelerated
forming the characteristic FI scallop (Branch and Gollub, 1974; Dews
1978; Ferster and Skinner, 1957; Lowe and Harzem, 1977), although
it should be noted that according to some investigators the transition
is abrupt, and the FI pattern is better described as break-and-run
(Schneider, 1969; Shull and Brownstein, 1970; Shull, Guilkey and
Witty, 1972). The postreinforcement pause, on the other hand, is
typically long often occupying about half to two-thirds of the
interval. The duration of the pause is systematically related to the
duration of the fixed interval, and it is affected by variables such
as reinforcer magnitude (Lowe, Davey and Harzem, 1974; Staddon, 1970a);
level of deprivation (Collier, 1962) drug effects (Branch and Gollub,
1974; Dews, 1968); and punishment of each response (Azrin and Holz,
1961).

Although the performance characteristics of FI schedules have
been studied extensively, determination of the duration of the post-
reinforcement pause is not yet fully understood. Consider, for example,
the following comparison with the performance that is typically
observed under interresponse-time-greater-than-t-sec (IRT>t) schedules.
Under an FI schedule the pause often occupies half or more of the
duration of the interval. Thus under an FI 60-sec schedule, for
example, almost every pause exceeds 20 sec; yet when a pause of 20
sec is necessary for reinforcement, i.e. under the IRT>20-sec schedule,
considerably fewer pauses of such length are observed, only half or
less of the interresponse times (IRT's) meeting the schedule criterion

and thereby ending in reinforcement (Harzem, 1969; Kramer and Rilling, 1970). Also, if FI and IRT>t schedules with the same parameter are compared, considerably fewer postreinforcement pauses matching in duration the schedule value are observed under the FI schedule than under the IRT>t schedule (Harzem, 1969; Kramer and Rilling, 1970; see also Richardson, 1973). Thus, in summary, although an organism can repeatedly pause for a given duration or longer on an FI schedule, it fails to pause for the same duration with the same high frequency when that pause duration is required for reinforcement on an IRT>t schedule. Conversely, although an organism can frequently meet the schedule criterion under an IRT>t schedule, its pauses are shorter under an FI schedule with the same parameter.

The main difference between the IRT>t and FI schedules is that pauses of a given duration or longer are required for reinforcement in the IRT>t schedule, whereas in the FI schedule there is no such requirement. The first experiment was designed to investigate possible interactions between FI and IRT>t schedules. Specifically, the question was asked: would the duration of the FI pause be increased if responses terminating longer pause durations were reinforced?

EXPERIMENT 1

METHOD

Subjects

Eight male hooded rats, approximately 12 weeks old at the start of the experiment, were individually housed and maintained at 80%

of their free-feeding weights. Water was freely available in the
home cages.

Apparatus

Four Lehigh Valley Model 142-25 chambers, with the right-lever
and both pellet dispenser and milk dipper in position, were used.
The milk dipper remained in the up position and operated at each
reinforcement, the dipping action taking approximately 1.0 sec. The
houselight remained off throughout the experiment. The experiment
was controlled by and the data were recorded and analysed on a NOVA
1200 computer.

Procedure

Lever-pressing responses were shaped in the first session. Sub-
sequently, the animals were placed on an FI 60-sec schedule in daily
sessions including weekends (First Baseline condition). Throughout
the experiment the FI reinforcer was a 45 mg Noyes pellet. When
inspection of cumulative records indicated that responding was stable,
the following stability criteria were applied: (i) variation in the
mean duration of postreinforcement pauses in 5 successive sessions less
than 10% of the mean duration for all 5 sessions; and (ii) variation
between response rates in each of the same 5 sessions less than 10%
of the mean rate for all 5 sessions. When according to these criteria
responding became stable, a second reinforcement contingency was added
while at the same time FI reinforcement continued. The response
terminating a postreinforcement pause was reinforced if the duration
of the pause exceeded 30 sec. For the added reinforcement two types

of reinforcer were used: a 45 mg Noyes pellet which was the same as
for FI reinforcement (Food condition), and 0.01 ml of 30% solution of
Nestle's condensed milk (Milk condition). Four animals (P6, P9, P11
and P15) were first placed on the Milk, and then on the Food condition.
The other four animals (P16, P17, P18, P19) were exposed to these
conditions in reverse order. Finally, added reinforcement was removed
and 15 further sessions were conducted on the FI 60-sec schedule
(Second Baseline). Sessions lasted 100 min or until reinforcements
occurred, whichever came first. Each change in experimental conditions
was carried out only after the stability criterion described above was
met. The number of sessions on each condition is shown in Table 1.

RESULTS AND DISCUSSION

Figure 1 shows the percentage of pauses following FI reinforce-
ment which were longer than 30 sec in the baseline FI 60-sec schedule
(Second Baseline), and in the Food and Milk conditions. When responses
terminating pauses longer than 30 sec were reinforced, the frequency
of such pauses declined in relation to their frequency on the FI
schedule. This decline was greater when FI reinforcement and added
reinforcement were the same, i.e. food, than when FI reinforcement and
added reinforcement were different, i.e. food and milk respectively.
This difference probably represents a confusion of the discriminative
control by the reinforcer in the Food condition (cf. Cruse, Vitulli
and Dertke, 1966). In this condition the presentation of the food
pellet signalled either of two different situations, depending on
whether reinforcement occurred on completion of a fixed-interval run,

Table 1

Experiment I: Number of Sessions, interquartile range of post-reinforcement pauses (sec.), and running rates (responses/min.) on each condition. BL_1: First Baseline FI 60-sec., BL_2: Second Baseline FI 60-sec. The order of conditions is shown top to bottom.

Animal	Condition	No. Sessions	Interquartile ranges of pauses following		Running rate following	
			FI rft.	Added rft.	FI rft.	Added rft.
	BL_1	25	29.0-54.5		41.4	
P6	MILK	35	23.5-36.5	3.0- 7.0	35.6	47.8
	FOOD	22	16.0-26.0	16.0-25.5	49.1	8.0
	BL_2	15	29.0-44.7		78.5	
	BL_1	25	25.0-46.5		61.8	
P9	MILK	35	22.0-31.0	12.0-20.0	53.4	52.5
	FOOD	22	16.0-22.0	17.5-25.5	56.6	18.8
	BL_2	15	25.7-40.5		92.6	
	BL_1	27	22.0-41.0		50.9	
P11	MILK	35	23.0-33.0	13.0-18.0	28.8	38.7
	FOOD	22	16.0-26.7	17.7-23.5	48.9	10.2
	BL_2	15	31.2-44.7		89.3	
	BL_1	25	28.5-60.0		33.4	
P15	MILK	35	24.1-36.0	10.7-23.0	33.2	49.6
	FOOD	22	23.0-34.2	25.0-36.0	44.3	12.4
	BL_2	15	34.0-61.0		93.3	
	BL_1	26	31.0-43.0		81.6	
P16	FOOD	35	18.0-29.0	8.5-24.7	56.4	12.7
	MILK	22	19.0-30.5	5.0-13.0	84.5	60.1
	BL_2	15	29.0-41.0		115.1	
	BL_1	26	15.0-34.5		61.4	
P17	FOOD	35	22.0-31.0	18.2-24.0	66.6	29.9
	MILK	22	25.7-32.0	3.6- 6.0	101.4	88.7
	BL_2	15	24.0-37.5		105.9	
	Bl_1	26	23.0-47.0		42.6	
P18	FOOD	35	7.0-31.0	4.7-16.1	41.6	8.4
	MILK	22	23.5-36.2	3.0- 4.0	50.9	68.3
	BL_2	15	17.5-47.7		71.5	
	BL_1	26	24.5-39.0		81.6	
P19	FOOD	35	22.0-34.0	28.0-33.7	56.4	13.9
	MILK	22	26.2-43.0	4.0- 6.2	84.5	75.7
	BL_2	15	41.0-54.0		115.1	

Figure 1. Experiment 1: Percentage of pauses
which exceeded 30 sec on the simple FI 60-sec
schedule (Second Baseline) and when responses
terminating such pauses were reinforced with
milk and with food. Data are from the last three
sessions on each condition.
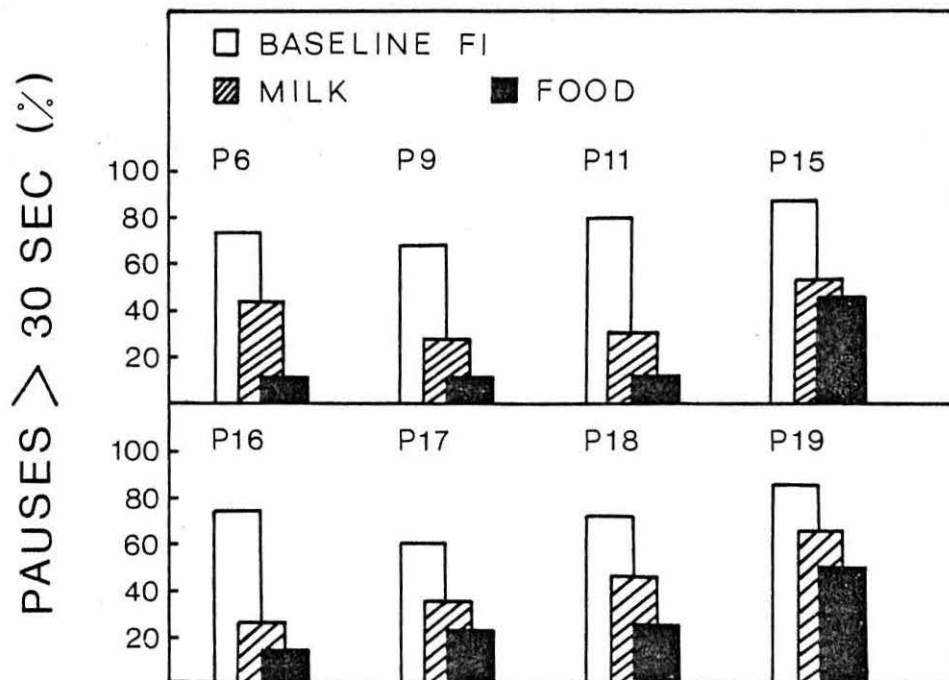
or on completion of a pause that met the added reinforcement
criterion.

Evidence of such discriminative control is seen in Figure 2
which shows the mean duration of the postreinforcement pauses in the
last 3 sessions of each condition. The interquartile ranges of these
durations, as well as running rates are given in Table 1. (The
running rates were calculated after excluding the pauses). With the
exception of one data point (Animal P17 the fixed baseline condition)
the pauses following FI reinforcement were longer on the simple FI
60-sec schedule than with either type of added reinforcement.

In the Milk condition, that is, when the added reinforcer was
different from the FI reinforcer, the pauses were longer following
FI reinforcement than following added reinforcement. The relationship
was more complex, however, in the Food condition, and depended on
which of the two conditions were experienced first by the animals.
If the animals had been previously trained on the Milk condition, the
postreinforcement pauses on the Food condition were of identical
duration regardless of whether they followed FI reinforcement or added
reinforcement. For animals who first experienced the Food condition,
on the other hand, there was a difference between the after effects
of FI reinforcement and added reinforcement. Even though the rein-
forcer was the same in the Food condition, the pause following FI
reinforcement was longer than that following added reinforcement. Thus,
there was an order-effect in the establishment of discriminative control
by the reinforcing stimuli. When the FI reinforcer and the added
reinforcer were identical, as in the Food condition, such discrimina-

Figure 2. Experiment 1: Mean duration of
postreinforcement pauses on the baseline FI
60-sec schedules (BL_1 and BL_2) and on the Milk
and Food conditions, Cross-hatched and filled
blocks indicate mean duration of postreinforcement
pauses that occurred following added milk and
food respectively; open blocks indicate mean
duration of postreinforcement pauses following
FI reinforcement. The sequence of conditions
is shown left to right in the abscissa.
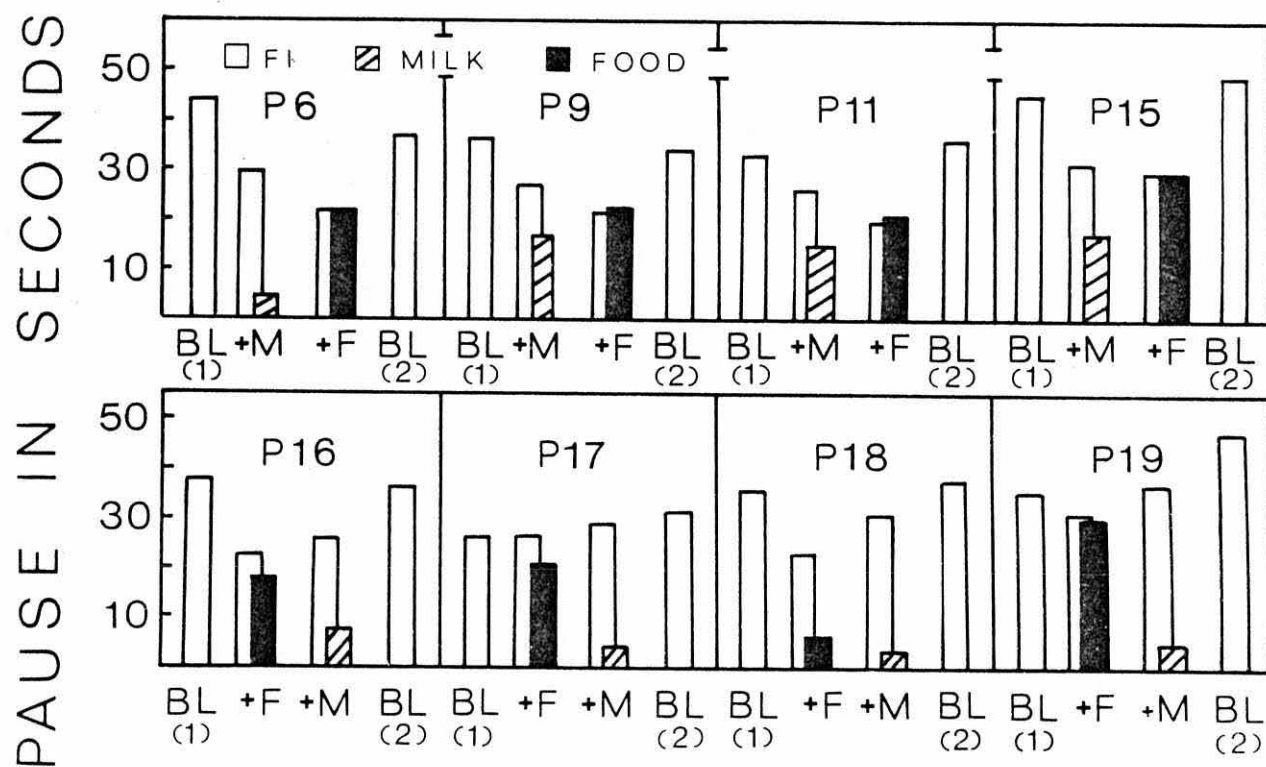
tive control could be based on the events that preceded reinforcement: added reinforcement was preceded by a pause 30 sec or longer whereas FI reinforcement was preceded by a run of responses. Discrimination based on these cues alone was not established, however, if the animals were first trained with two different kinds of reinforcers, and initially learned a discrimination on the basis of the differences between the types of reinforcers; it is possible that the failure of the discrimination to develop in these animals may represent an instance of "blocking" (cf. Mackintosh 1974).

CHAPTER SIX

ALTERNATIVE SCHEDULES OF REINFORCEMENT

In Experiment 1, a confusion of the discriminative effects of
reinforcement was observed since the contingencies that prevailed
after reinforcement were not always the same. Following FI reinforce-
ment either a minimum pause of 30 sec, or a minimum interval of 60 sec
regardless of intervening responses, led to reinforcement; following
added reinforcement an interval less than 30 sec, regardless of
intervening responses, led to reinforcement. Confusion of these
contingencies was reduced if they were initiated by different kinds
of reinforcers. In the present experiment, on the other hand,
possibility of such confusion was eliminated by holding constant the
contingencies that prevailed after every reinforcement. The minimum

pause duration required for added reinforcement was varied over
a wide range of values.

EXPERIMENT 2

METHOD

Subjects

Four naive male hooded rats, approximately 90 days old at the
start of the experiment, were individually housed and maintained
at 80% of their free-feeding weights. Water was freely available in
the home cages.

Apparatus and Procedure

The apparatus was the same as in Experiment 1. Throughout this
experiment the reinforcer was a 45 mg Noyes pellet. In the first
session lever-pressing responses were shaped. Starting with the second
session the animals were trained on an FI 60-sec schedule until
responding became stable (First Baseline). The animals were then
placed on an alternative fixed-interval 60-sec interresponse-time-
greater-than-X-sec (alt FI 60-sec IRT>X-sec) schedule. That is,
following each reinforcement, either the next response was reinforced
provided it occurred after a pause of at least X sec, or, if the pause
was shorter than X sec, the first response to occur after an interval
of 60 sec from the previous reinforcer was reinforced. (Note that
this is a modified version of the alternative schedule described by
Ferster and Skinner, 1957. Strictly speaking the present schedule is
a "reinforcement-initiated alternative schedule"). Thus, unlike

Experiment 1, each reinforcement initiated the same two contingencies.

The FI value was held constant at 60 sec throughout the experiment but the IRT≻t value (X) was 30, 20, 40, 10 and 50 seconds occurring in that order. Each change in the value of X was made after the stability criterion described in Experiment 1 was met. Finally, the IRT≻t contingency was removed and 10 further sessions were conducted on an FI 60-sec schedule (Second Baseline). The number of sessions on each condition is shown in Table 2. The sessions were conducted daily and each session lasted 100 min or until 100 reinforcements occurred, whichever came first.

RESULTS AND DISCUSSION

Figure 3 shows cumulative records of the performance of Animal P2 in the last session on each schedule value and on the second FI 60-sec baseline schedule. The records are representative of the performance of other animals. Runs of successive IRT≻t reinforcements occurred on low values of the IRT≻t schedule, such IRT≻t reinforcements being less frequent as the schedule value increased. The FI response pattern consisted mainly of characteristic scallops but there were also some break-and-run patterns especially with high values of IRT≻t.

Taking only the FI segments of performance, i.e. interreinforcement intervals with pauses less than the IRT≻t criterion, Figure 4 shows the running rate and overall rate of responses as functions of the value of the IRT≻t schedule. The running rate of responses

Table 2

Experiment 2 : Number of sessions, interquartile ranges of post-reinforcement pauses (sec), and mean interreinforcement interval (sec.) on each condition. BL_1: First Baseline FI 60-sec. BL_2: Second Baseline FI 60-sec.

Animal	Schedule alt FI 60 IRT>X-sec X =	No. Sessions	Interquartile ranges of pauses following		Mean Interreinforcement interval
			FI rft.	IRT>X rft.	
	10	19	15.2-19.7	12.0-16.0	19.6
	20	17	18.0-23.0	17.2-21.0	44.6
	30	38	23.2-33.0	22.0-29.0	53.0
P2	40	12	27.7-38.0	28.2-34.2	57.8
	50	12	27.0-41.2	18.0-37.7	59.4
	BL_1	18	25.0-44.5		60.0
	BL_2	10	33.0-49.0		60.0
	10	18	12.2-18.0	13.0-18.0	19.4
	20	17	18.0-25.7	21.0-26.0	34.6
	30	37	28.0-35.2	29.0-33.0	44.6
P8	40	13	34.0-44.0	33.6-40.7	56.4
	50	12	18.0-44.0	37.0-45.0	57.8
	BL_1	18	32.0-48.5		60.0
	BL_2	10	31.5-48.0		60.0
	10	19	8.0-11.0	9.0-12.0	40.4
	20	17	8.0-19.0	7.2-19.0	54.6
	30	35	5.0-28.2	4.0-23.2	56.2
P10	40	12	19.5-34.0	20.5-32.0	58.6
	50	12	7.7-40.5	14.5-30.0	58.4
	BL_1	18	20.5-37.0		60.0
	BL_2	10	12.5-46.0		60.0
	10	19	9.0-11.5	9.2-12.2	35.2
	20	17	13.0-18.0	13.0-18.0	45.2
	30	37	16.0-25.0	14.0-22.0	57.8
P13	40	14	22.0-32.7	17.7-21.0	58.8
	50	12	14.7-25.0	*	60.0
	BL_1	18	27.5-43.0		60.0
	BL_2	10	15.5-28.5		60.0

*No interquartile ranges are shown since the number of post-reinforcement pauses was small.(<4 per session).

Figure 3. Experiment 2: Cumulative records
obtained from Animal P2 in the last session
with each alt FI IRT>t schedule value, and on
the second baseline FI 60-sec schedule. The
numbers next to each record indicate the IRT>t
value.

500 RESPONSES

10

20

30

40

50
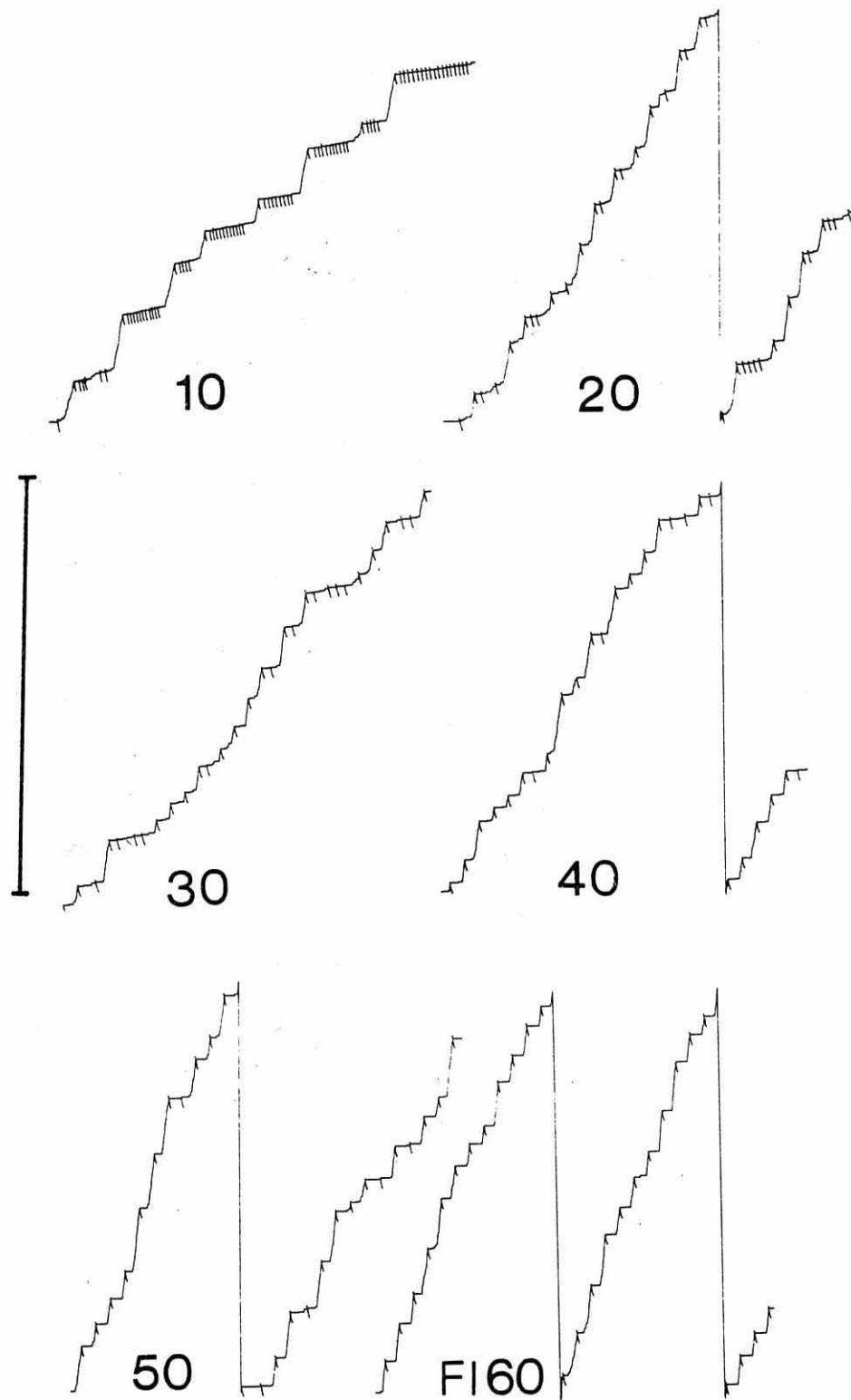
FI60

25 MINUTES

Figure 4. Exepriment 2: Mean running rates,
and overall response rates in the FI segments,
(i.e. interreinforcement intervals with pauses
less than the IRT>t criterion) of the alt FI
IRT>t schedules. Data points from the FI 60-sec
condition (Second Baseline) are connected by
broken lines. Data are from the last three
sessions, on each condition.
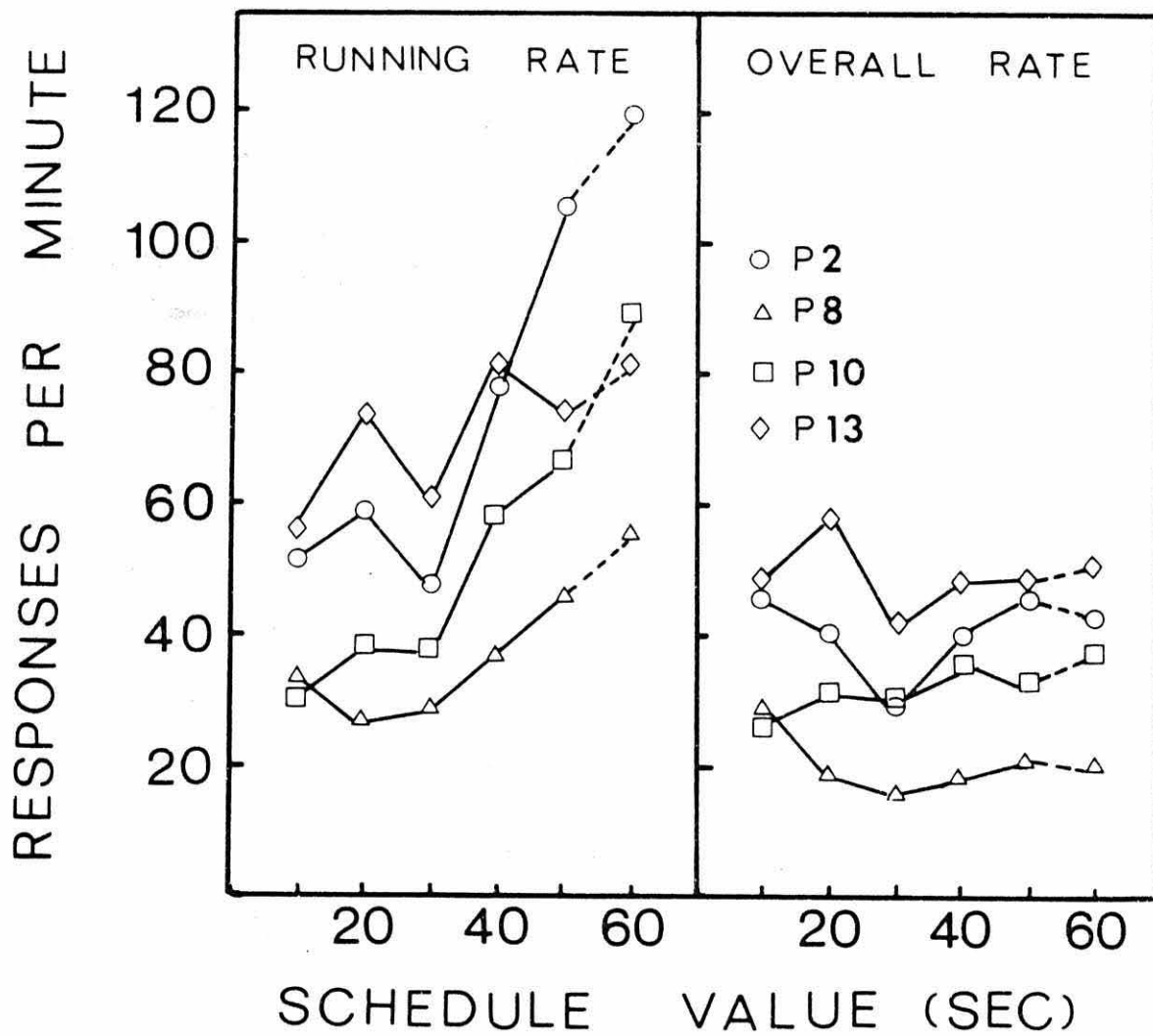
remained approximately the same with IRT>t values up to 30 sec, but increased as a function of IRT>t value beyond that (cf. Lowe, Davey and Harzem, 1974; Lowe and Harzem, 1977). Schedule effects were masked, however, in the overall rate measure which remained more or less the same at all IRT>t values. Such masking of relationships by the measure of overall rate has been previously observed in other situations; i.e. Lowe, Davey and Harzem (1974), Priddle-Higson, Lowe and Harzem (1976) and Timberlake (1977).

On the alternative schedules with all values of the IRT>t schedule (except one data point for Animal P.13), the proportion of pauses meeting the IRT>t criterion was less than the proportion of such pauses on the simple FI 60-sec schedule (Figure 5). Thus, as in Experiment 1, addition of the IRT>t contingency resulted in a shortening of post-reinforcement pauses. Even with the 10-sec criterion, for example, although almost all of the pauses on FI 60-sec were longer than 10 sec, fewer such pauses occurred when the IRT>10-sec contingency was in effect.

Figure 6 shows mean duration of all postreinforcement pauses as a function of IRT>t value. These data are compared with the mean duration of post reinforcement pauses that were observed on simple IRT>t schedules. (see procedure of Experiment 3). For all animals the functions obtained on different values of the alt FI IRT>t schedule were similar to the functions obtained on comparable values of the simple IRT>t schedule, despite considerable differences in mean interreinforcement intervals between the two schedules (see Tables 2 and 4). As Figure 7 shows, because of the FI 60-sec alternative, as IRT>t value

Figure 5. Experiment 2: percentage of pauses
greater than the IRT>t criterion on the simple
FI 60-sec schedule (Second Baseline) shown by
unfilled blocks, and when responses terminating
such pauses were reinforced on alt FI IRT>t
schedules (filled blocks). Data are from the
last three sessions on each IRT>t value.
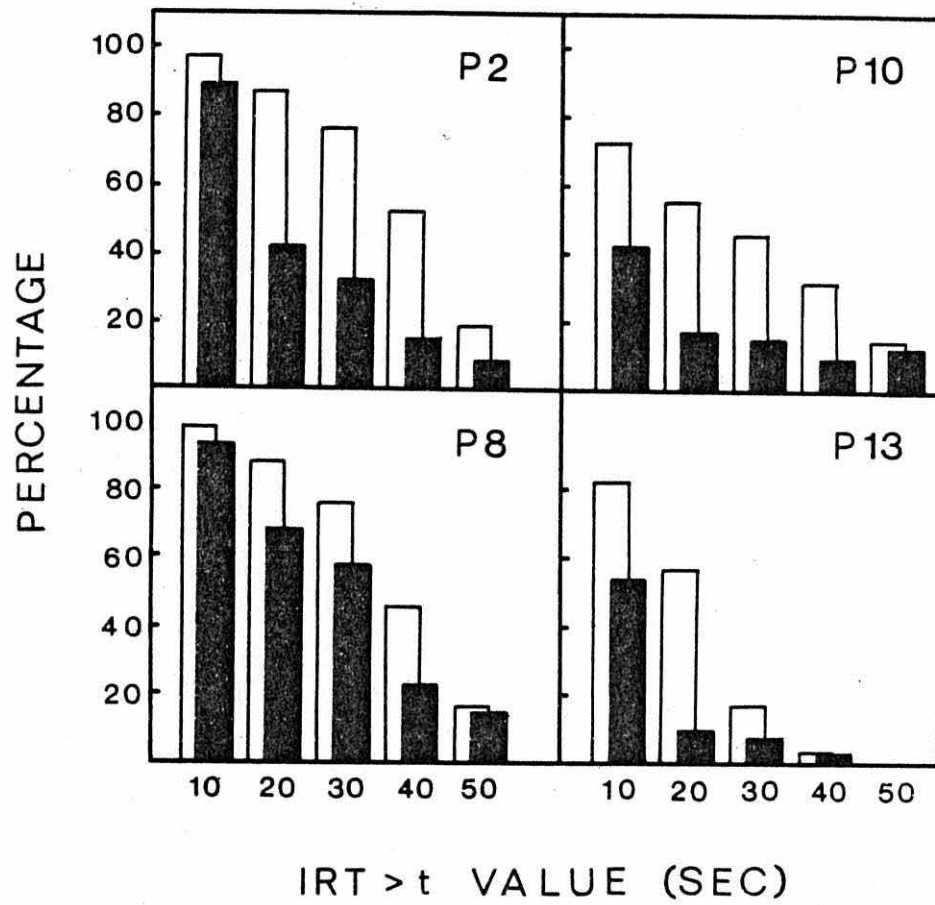
PERCENTAGE

IRT > t VALUE (SEC)

Figure 6. Experiment 2: Mean duration of
postreinforcement pauses as a function of
IRT>t schedule value in the alt FI IRT>t
schedule (crosses) and on simple IRT>t
schedules (filled circles). Unconnected
circles indicate redetermination points for
IRT>t values. Unconnected diamonds in the
left and right of each panel are pause dura-
tions on the First and Second Baseline FI
60-sec schedules respectively. The broken
line indicates the IRT>t criterion above which
the response terminating the pause produced
reinforcement. Note that both axes are in
log scales. Data are from the last three
sessions on each condition.
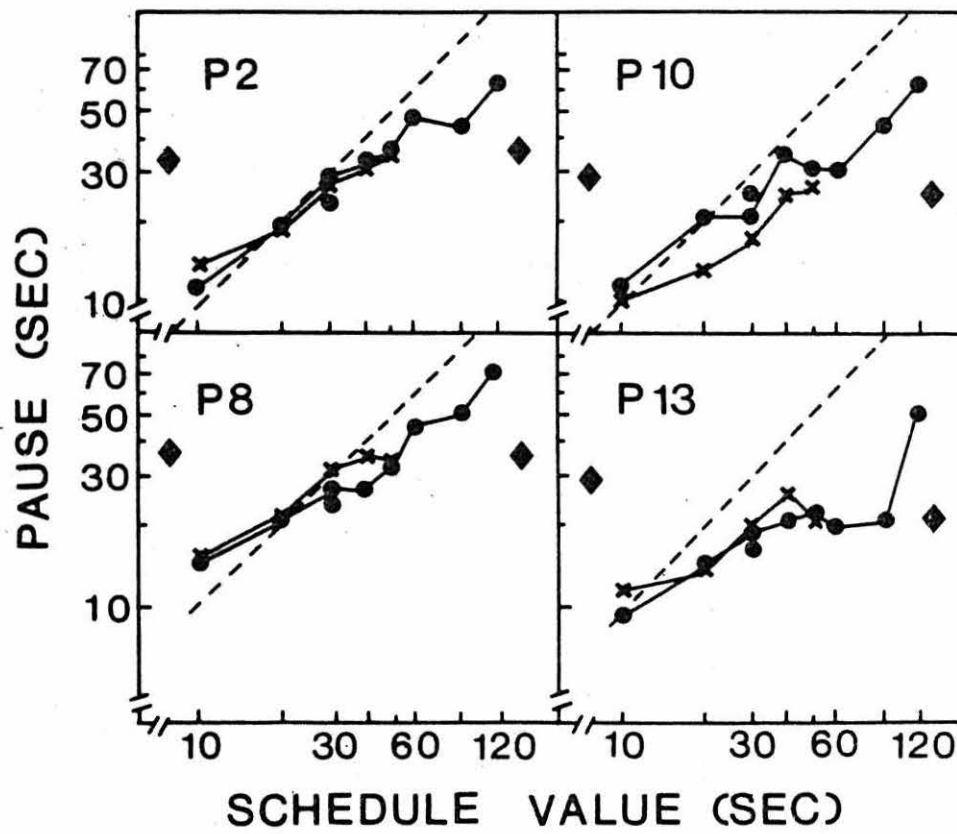
was increased there was little increase in interreinforcement interval in the alt FI IRT>t schedules, compared with that occurring on the simple IRT>t schedules. Thus, because pause was virtually the same for a given IRT>t value, irrespective of whether or not there was an FI 60-sec alternative, the Pause-interreinforcement interval functions are different for the alt FI IRT>t schedules as compared to that on simple IRT>t schedules i.e. they are much steeper. The postreinforce-ment pause functions of Figure 6 are similar to those previously reported for interresponse times on temporal schedules (cf. Catania, 1970). Thus it appears that pause durations in the present experiment were controlled entirely by the IRT>t contingency.

There remains, however, the possibility that individual pauses may nevertheless have been differently affected depending on whether they followed an FI run of responding or an IRT>t pause. Figure 8 shows that there was no such differential effect, at each schedule value the pauses being of similar duration irrespective of whether they were preceded by FI or IRT>t reinforcement. Moreover, there was also no systematic relationship between the number of responses emitted in FI runs and the duration of the subsequent pause.

These findings were extended in the next experiment where the IRT>t value was held constant and the FI value was systematically manipulated.

Figure 7. Experiment 2: Mean duration of
postreinforcement pauses as a function of
interreinforcement interval in the alt FI
IRT>t schedule (crosses) and on simple IRT>t
schedules (filled circles). Unconnected
circles indicate redetermination points for
IRT>t values. Note that both axes are in
log scales. Data are from the last three
sessions on each condition.

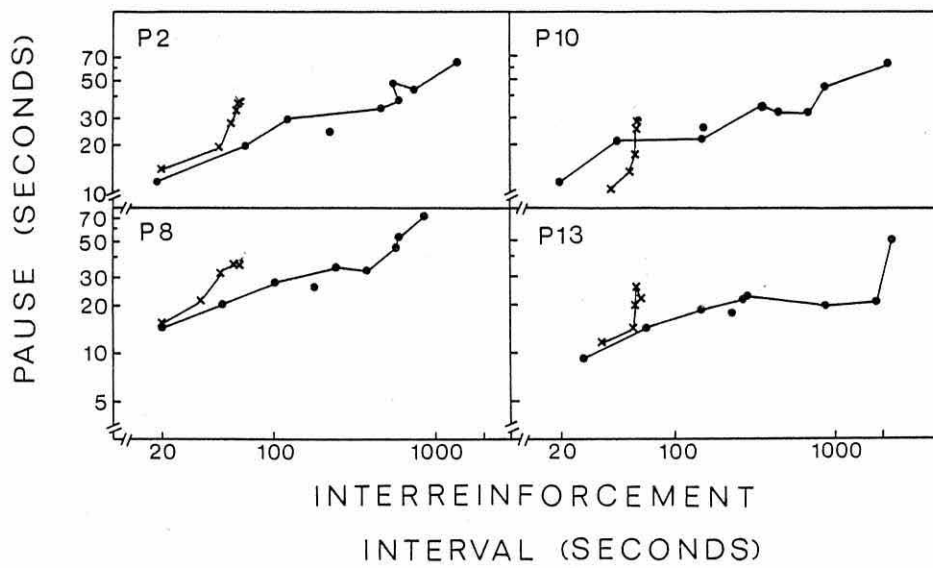Figure 8. Experiment 2: Mean duration of
pauses following FI reinforcement (filled
circles) and following IRT>t reinforcement
(crosses). Numbers indicate the mean number
of responses in the preceding FI run. Broken
lines show the IRT>t criterion above which the
response terminating the pause produced rein-
forcement. Note that both axes are in log
scales. Data are from the last three sessions
on each condition.
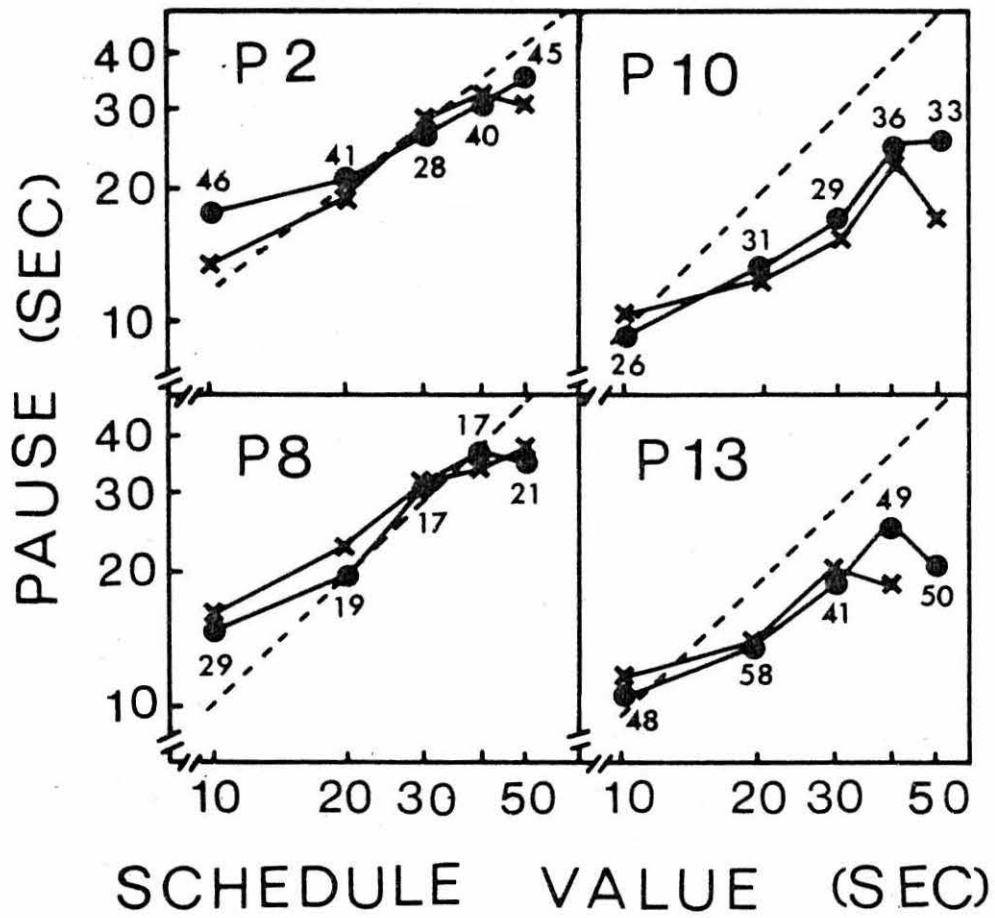
EXPERIMENT 3

METHOD

Subjects and apparatus were the same as in Experiment 2.
Immediately following the final condition of Experiment 2 the
animals were placed on an IRT>t 20-sec schedule until responding
became stable. (First Baseline). An FI contingency was then added,
so that the schedule was alt FI X-sec IRT>20-sec. Thus, throughout
the experiment the IRT>t value was 20 sec and the FI value (X) was
60, 30, 120, 15, 240 and 480 seconds, in that order. Finally, 11
further sessions were conducted on the IRT>20-sec schedule (Second
Baseline). Each schedule change was made after the stability criterion
was met, the criterion being the same as in previous experiments.
The number of sessions on each condition is shown in Table 3. All
other details of the procedure were the same as in Experiment 2.

On completion of this phase, the animals were placed on simple
IRT>t and FI schedules with all the schedules used in the alternative
schedules of Experiments 2 and 3. Each schedule change was made after
the stability criterion was met. The order of schedules, number of
sessions on each schedule, interquartile ranges of the postreinforce-
ment pauses, and mean interreinforcement interval on each condition
are given in Table 4.

RESULTS AND DISCUSSION

Figure 9 shows sample cumulative records of the performance of
Animal P2 in the last session of every schedule value. These records

Table 3

Experiment 3 : Number of sessions, interquartile ranges of post-reinforcement pauses (sec) and mean interreinforcement intervals (sec) on each condition.

Animal	Schedule alt FI X-sec IRT >20-sec X =	No. Sessions	Interquartile ranges of pauses following FI rft.	IRT >20 sec	Interreinforcement interval
	15	10	8.6-12.1	*	16.4
	30	8	14.0-18.1	14.0-20.2	27.4
	60	10	13.9-19.9	13.8-20.6	42.9
	120	10	17.7-22.0	18.5-23.9	55.9
P2	240	15	14.0-18.7	17.6-22.1	122.6
	480	20	15.9-19.7	17.5-22.2	238.0
	BL$_1$	18		21.3-25.6	35.6
	BL$_2$	11		19.6-24.2	44.7
	15	10	9.6-11.4	*	16.5
	30	8	12.0-21.7	17.1-23.9	32.6
	60	10	14.0-20.0	16.0-23.0	41.3
	120	10	13.5-22.0	16.0-23.8	52.0
P8	240	15	12.0-22.0	17.1-23.2	84.9
	480	20	16.1-19.8	18.0-24.0	244.3
	BL$_1$	18		13.7-22.4	54.2
	BL$_2$	11		19.6-23.7	41.1
	15	10	4.1- 7.3	*	15.5
	30	8	7.2-10.9	8.2-11.8	29.3
	60	10	8.3-17.6	7.1-14.0	54.2
	120	10	10.0-20.3	7.0-18.1	97.5
P10	240	15	8.3-17.5	10.1-19.0	194.5
	480	20	6.8-18.9	*	383.3
	BL$_1$	18		11.6-21.2	86.1
	BL$_2$	11		4.7-18.2	102.3
	15	10	4.0- 9.1	*	15.5
	30	8	8.1-16.0	10.3-18.7	30.6
	60	10	7.7-15.9	12.2-18.9	53.3
	120	10	6.0-13.1	9.4-17.1	107.9
P13	240	15	6.9-15.3	*	225.2
	480	20	9.3-17.5	*	418.6
	BL$_1$	18		7.2-17.1	123.8
	BL$_2$	11		12.7-24.0	54.8

*Interquartile ranges are not given since the number of pauses was small (< 4 per session).

Table 4

Number of sessions, interquartile ranges of postreinforcement pauses (sec) and mean interreinforcement intervals (sec) for simple FI and IRT>t schedules. The order of schedule values is shown top to bottom. IRT>t schedules were run after the completion of all FI sessions.

Animals	FI (sec)	No. Sessions	Interquartile ranges of pauses	Inter-reinforcement interval	IRT>t (sec)	Sessions	Interquartile ranges of pauses	Inter-reinforcement interval
P2	60	14	40.8- 57.4	60.0	30	14	18.2-28.4	214.3
	30	12	15.0- 28.7	30.0	20	10	18.6-21.3	65.2
	120	18	36.5- 68.0	120.0	40	12	31.5-39.1	461.5
	480	17	97.0-195.5	480.0	10	8	9.0-12.7	18.7
	15	12	9.0- 15.0	16.0	50	14	33.1-40.0	600.0
	240	18	43.5-100.6	240.0	30	10	26.8-31.2	120.0
	120	16	43.4- 65.4	120.0	60	12	34.5-55.3	537.1
	480	24	99.9-224.5	480.0	120	14	39.2-81.6	1369.0
	15	8	9.0- 15.8	16.0	90	12	27.6-54.9	714.0
P8	60	14	22.9- 43.6	60.0	30	14	21.3-33.0	181.8
	30	12	16.8- 24.2	30.0	20	10	18.3-22.7	46.1
	120	18	39.0- 75.0	120.0	40	12	24.0-22.7	240.0
	480	17	66.0-191.2	480.0	10	8	10.0-16.8	20.0
	15	12	9.8- 13.4	16.0	50	14	20.3-41.7	375.0
	240	18	49.8-107.5	240.0	30	10	21.7-31.3	100.0
	120	16	43.5- 81.5	120.0	60	12	22.9-55.9	562.1
	480	24	82.2-193.6	480.0	120	14	36.2-96.0	843.0
	15	8	8.5- 15.5	16.0	90	12	36.1-60.7	588.0
P10	60	14	21.7- 44.7	60.0	30	14	17.8-28.7	157.9
	30	12	9.3- 17.6	30.0	20	10	18.9-21.3	46.1
	120	18	31.0- 70.5	120.0	40	12	28.8-39.9	352.9
	480	17	59.0-130.0	480.0	10	8	9.6-12.3	19.4
	15	12	5.5- 9.6	15.0	50	14	15.6-40.3	428.6
	240	18	41.5- 97.5	240.0	30	10	16.0-26.8	175.0
	120	16	36.4- 84.4	120.0	60	14	17.5-37.4	687.4
	480	24	36.0-117.5	480.0	120	14	*	2083.7
	15	8	5.1- 8.6	15.5	90	12	24.2-64.5	847.8
P13	60	14	8.9- 19.6	60.0	30	12	12.1-19.6	230.8
	30	12	5.5- 12.1	30.0	20	10	9.4-19.4	67.4
	120	18	15.5- 48.5	120.0	40	12	11.2-19.4	260.9
	480	17	19.0- 81.0	480.0	10	8	6.9-26.6	27.3
	15	12	5.0- 10.0	15.0	50	14	14.0-23.7	290.9
	240	18	15.1- 30.1	240.0	30	12	10.7-22.8	150.0
	120	16	15.3- 50.6	120.0	60	14	12.6-22.5	876.0
	480	24	14.8- 30.4	480.0	120	14	*	2229.4
	15	8	5.5- 8.3	15.5	90	12	14.5-22.5	1813.0

*Interquartile ranges are not given since the number of pauses was small (<4 per session).

Figure 9. Experiment 3: Cumulative records
obtained from Animal P2 in the last session with
each alt FI IRT>t schedule value. The numbers
next to each record indicate the FI value.
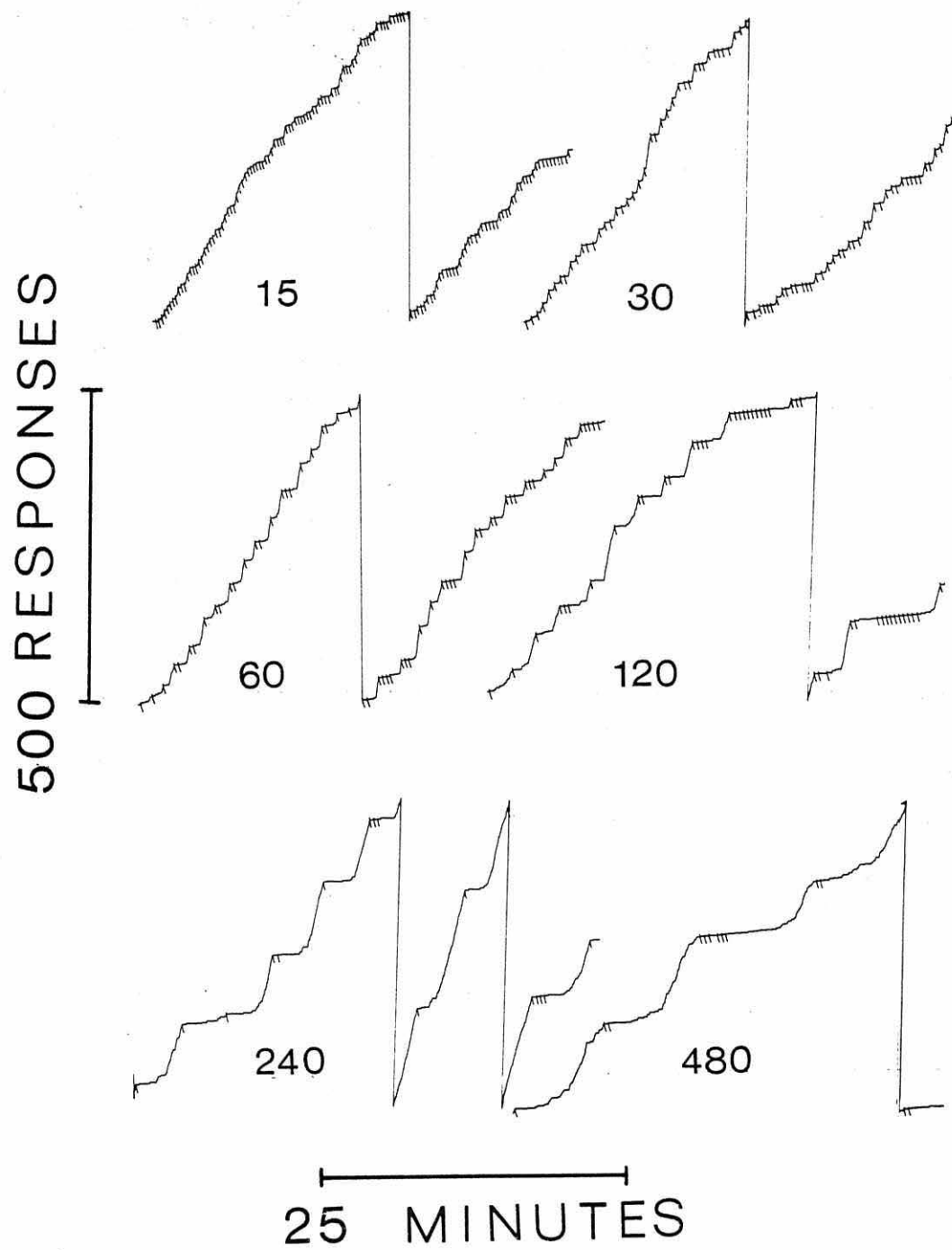
are representative of the performance of other animals. With each
value of the schedule characteristic FI performance occurred, consisting
mainly of scallops. As the value increased, there was a decline in
the absolute number of reinforcements that occurred on the IRT>t schedule
in each session and in the overall frequency of reinforcement.

The running rate and overall rate of responses that occurred in
the FI segments, i.e. interreinforcement intervals with pauses shorter
than the IRT>t criterion, are shown in Figure 10. Both the running rate
and overall rate were negatively accelerated decreasing functions of
the FI value, (cf. Schneider, 1969; Starr and Staddon, 1974).

As in the previous experiments, the proportion of pauses that met
the IRT>t criterion of 20 sec was greater on the simple FI schedules than
on the comparable value of the alt FI IRT>t schedule (Figure 11); this
was the case at all FI values with the exception of P.13 on the 30-sec
and 60-sec values. Figure 12 shows the mean duration of all post-
reinforcement pauses, regardless of FI or IRT>t reinforcement, as a function
of FI schedule value. (See Table 3 for interquartile ranges). These
data are compared with the postreinforcement pause durations that were
observed on the simple FI schedules, with comparable schedule values.
On simple FI schedules the postreinforcement pause duration was an
increasing function of the schedule parameter (cf. Lowe and Harzem, 1977;
Sherman, 1959). The pause durations in the alt FI IRT>t schedules,
however, were maintained at or below the IRT>t value of 20 sec regardless
of the value of the FI schedule, even with values as long as 480 sec,
and were of the same duration as pauses on the two baseline IRT>20-sec.
Thus, in this experiment, as well as in Experiment 2, the IRT>t con-
tingency set the upper limit to the durations of the postreinforcement

Figure 10. Experiment 3: Mean running response

rates and overall response rates in the FI

segments, i.e. interreinforcement intervals with

pauses less than the IRT>t criterion of the alt

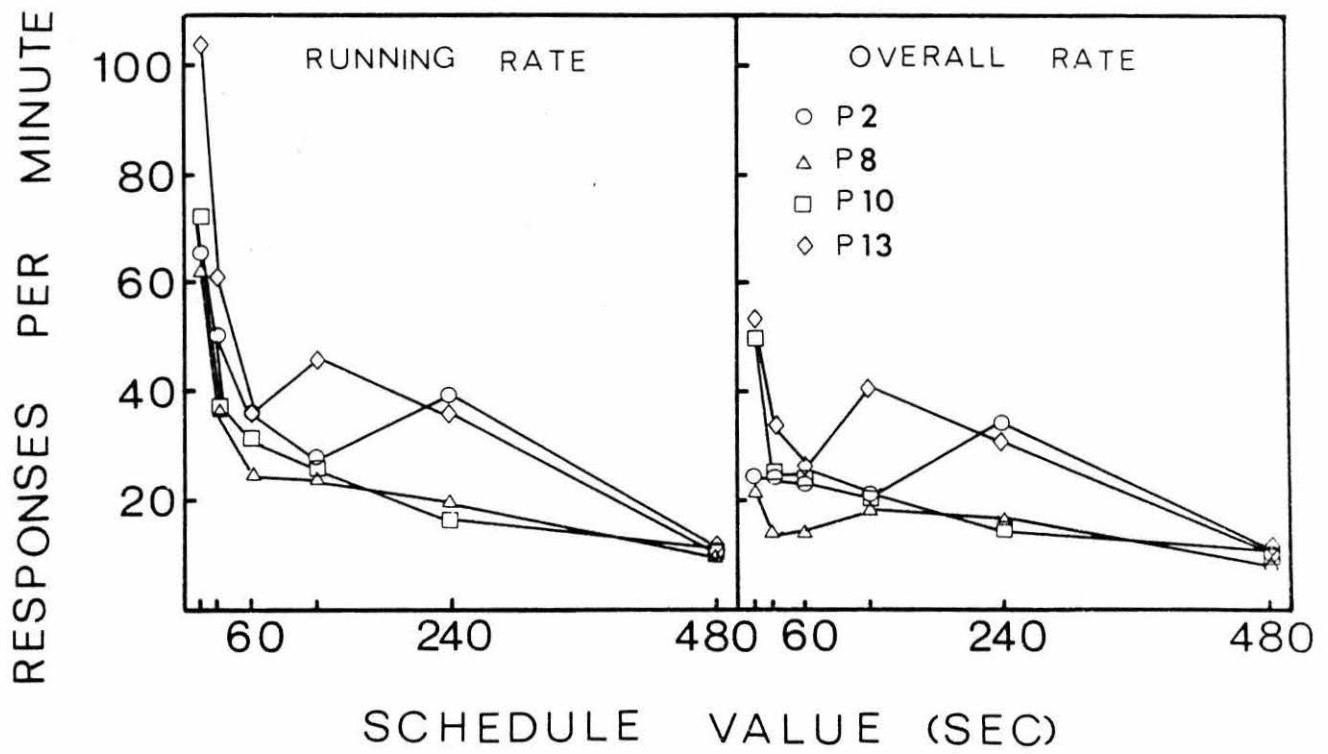FI IRT>t schedules. Data are from the last three

sessions on each schedule value.

Figure 11. Experiment 3: Percentage of pauses

greater than the IRT>t criterion of 20 sec on the

simple FI schedules (unfilled blocks) and on comparable

alt FI IRT>t schedules (filled blocks). Data are from
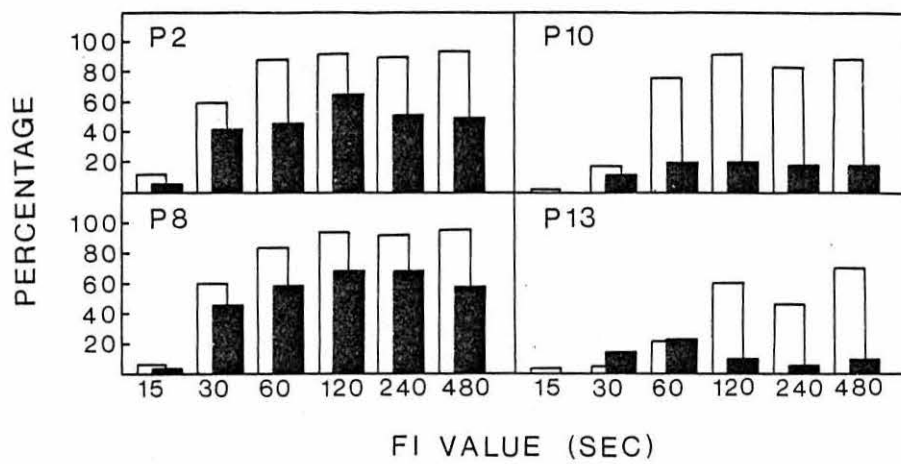
the last three sessions on each FI value.

Figure 12. Experiment 3: Mean duration of post-
reinforcement pauses as a function of FI schedule
value in the alt FI IRT>t schedule (crosses) and
on simple FI schedules (filled circles). Unconnected
circles indicate redetermination points for FI values.
Unconnected diamonds in the left and right of each
panel are pause durations on the First and Second
Baseline IRT>t schedules respectively. The broken
line indicates the IRT>t criterion above which the
response terminating the pause produced reinforcement.
Note that both axes are in log scales. Data are from
the last three sessions on each condition.
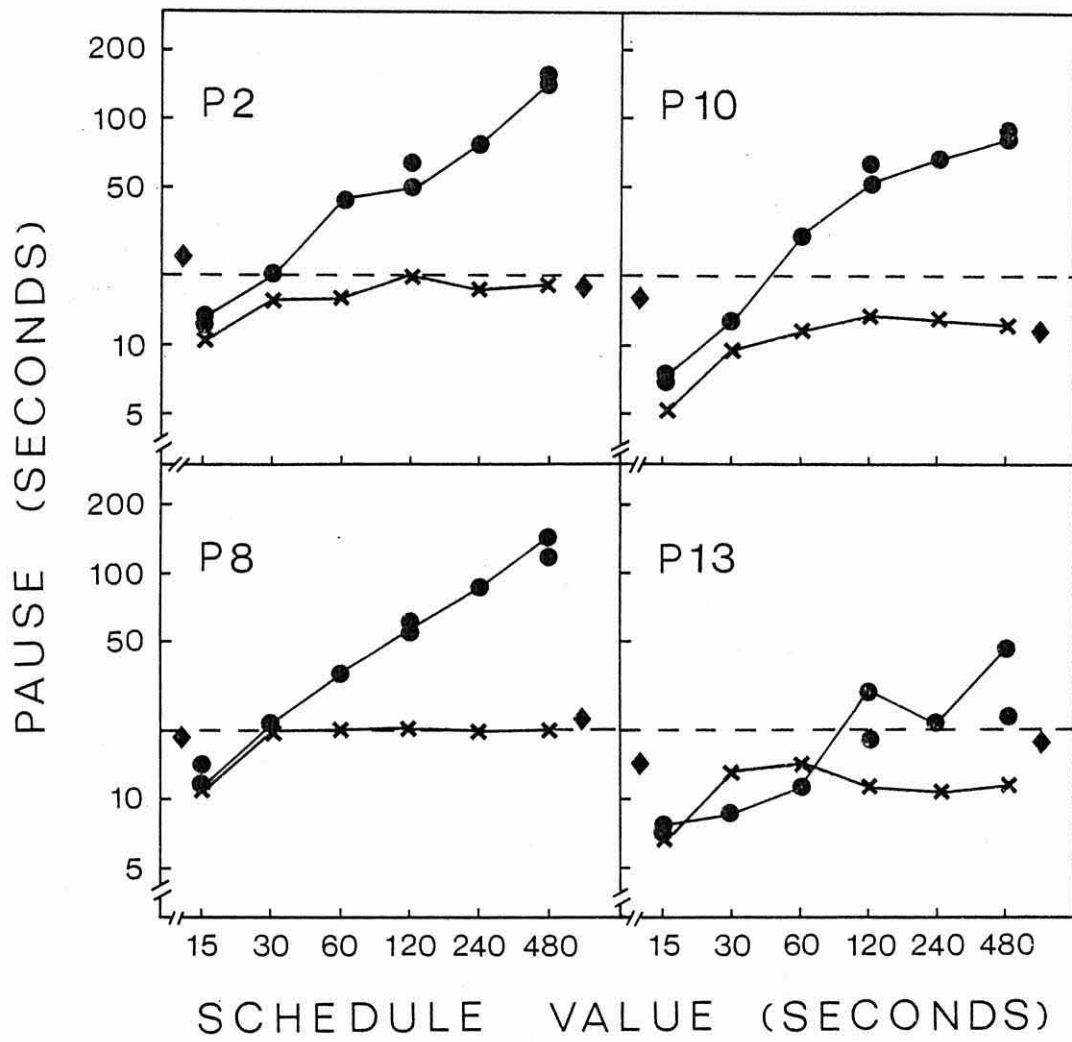
pauses. Table 3 shows that, contrary to some suggestions (Berryman and Nevin, 1962; cf. Nevin, 1973), the duration of the postreinforcement pause was not, on the alt FI IRT>t schedules, directly related to the arithmetic mean interreinforcement interval.

Figure 13 shows that though on the simple FI schedules there was a progressive increase in Postreinforcement Pause as interreinforcement interval increased, on the alt FI IRT>t schedules although there was an increase in Pause between the first two points (which corresponds to FI values of 15 and 30-sec) there was no subsequent increase in pause despite considerable increases in interreinforcement interval. Thus, as in Experiment 2 (cf. Figure 7) the two schedules (alt FI IRT>t and simple FI in this case) produced different Pause-interreinforcement interval functions.

As in Experiment 2, the individual pauses were not differently affected according to whether they followed an FI run of responding or an IRT>t pause. Figure 14 shows that at each FI value the pauses were of similar duration regardless of whether they were initiated by an FI or an IRT>t reinforcement. There was also no relationship between the number of responses in an FI run and the duration of the postreinforcement pause that followed that run.

GENERAL DISCUSSION

Control of the Postreinforcement Pause

The present results, especially the results of Experiment 1, provide further evidence that the duration of the postreinforcement pause is controlled by the discriminative properties of the event

Figure 13. Experiment 3: Mean duration of post-
reinforcement pauses as a function of interreinforcement
interval in the alt FI IRT>t schedule (crosses) and on
simple FI schedules (filled circles). Unconnected
circles indicate redetermination points for FI
values. Note that both axes are in log scales. Data are from
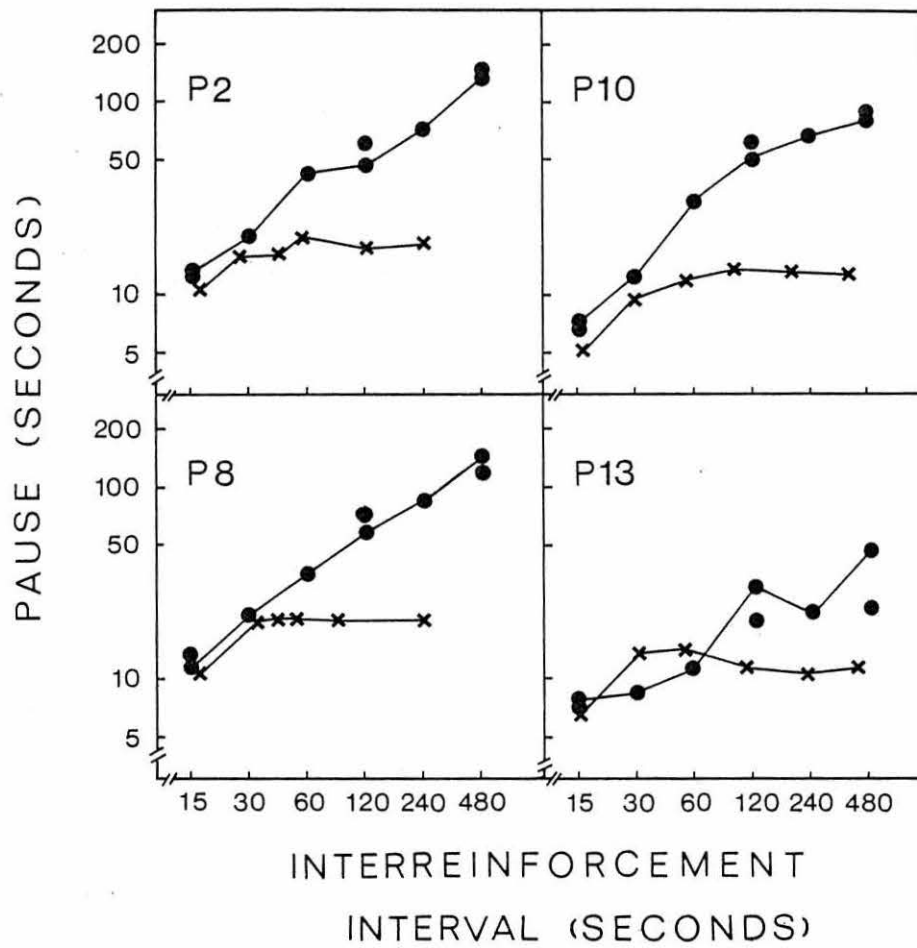the last three sessions on each condition.

Figure 14. Experiment 3: Mean duration of pauses following FI reinforcement (filled circles) and following IRT>t reinforcement (crosses). Numbers indicate the mean number of responses in the preceding FI run. Broken lines show the IRT>t criterion above which the response terminating the pause produced reinforcement. Note that both axes are in log scales. Data are from the last three sessions of each condition.
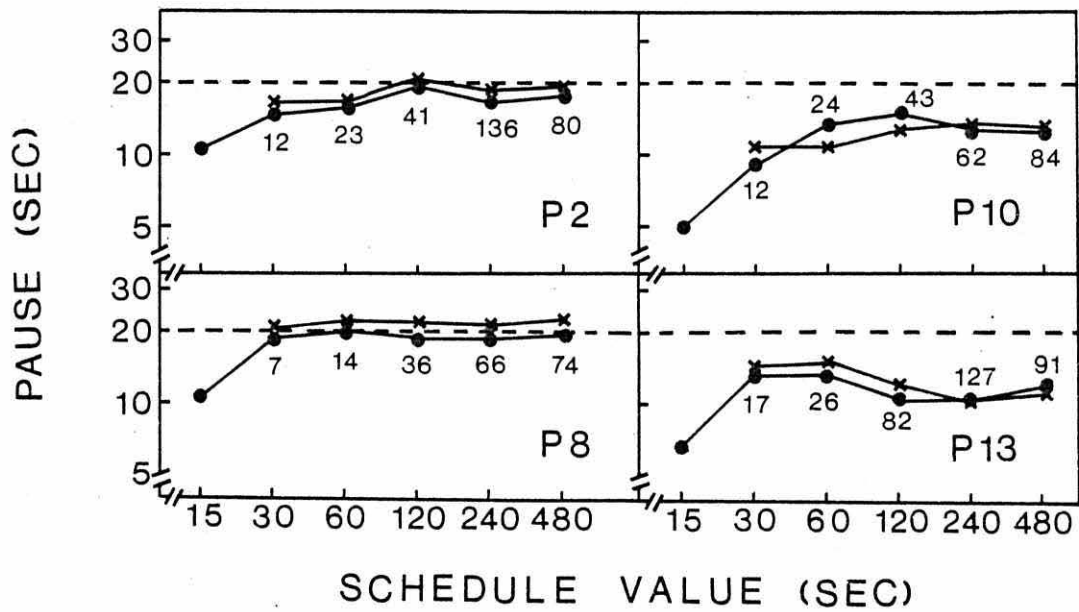
initiating that pause (cf. Cruse, Vitulli and Dertke 1966; Ferster and Skinner, 1957; Skinner, 1938). In simple schedules, i.e. where only responses and reinforcement are involved and not other discriminative stimuli, the delivery of food can function both as the discriminative stimulus initiating the pause, and in marking the end of the interval to which the postreinforcement pause is related. (See Harzem, Lowe and Priddle-Higson, 1978). It is not necessary, however, for these two functions to be combined in the same stimulus; the event initiating the pause may be a stimulus other than the reinforcer. Zeiler (1972) presented a different stimulus in place of the reinforcer on a percentage of the occasions on an FI schedule, and found that the FI pattern of responding was maintained in the intervals following the stimulus, as well as following reinforcement.

Given that the reinforcer functions as a discriminative stimulus in initiating the post-reinforcement pause, there remains the question of how the duration of that pause is determined. In the present study when responses terminating a pause which exceeded a criterion duration were reinforced the proportion of such pauses occurring on the FI schedule decreased, rather than increased. A plausible explanation explanation of this effect is that in those situations where the FI value was greater than the IRT>t value, the event initiating the pause set the occasion for pausing for a period related to the IRT>t criterion and not exceeding it. That is to say, whether reinforcement controls the pause that occurs on the FI schedule or on the IRT>t schedule is determined by the shorter of the two pauses.

The schedules used in the present experiments resemble in some respects the two-valued FI schedules of Catania and Reynolds (1968) where responses were reinforced according to either a long FI (240 sec) or a short FI (30, 90 or 210 sec, across conditions). When responses were reinforced at 30 and 240 sec, response rates increased to an asymptote near 30 sec., then declined, and then increased again as 240 sec. approached. Even a low probability of reinforcement at an early time increased substantially the probability of a response at that time (see also Ferster and Skinner, 1957). The present data showed a similar relationship when the early opportunity is schedules by an IRT>t dependency. Logan (1967) programmed two equally likely IRT>t values for rats. The actual value in effect was unpredictable after each reinforcement. The animal's postreinforcement pause was appropriate to the smaller of the two IRT>t values rather than an average of the two. These data are thus consistent with the account suggested by Catania and Reynolds (1968) and Shull and Guilkey (1976), namely, that the probability of a response increases as a function of proximity to the time at which that response is reinforced; Lattal and Bryan (1976) have also shown that when response independent food is presented early in the interval on FI schedules the duration of the postreinforcement pause is greatly reduced. In this study both the reinforcer and the response independent food were identical and there was no evidence that the animals could distinguish between the two i.e. a "confusion effect" similar to that observed in Experiment 1. Shull and Guilkey (1976) attempted to directly reinforce pausing on FI schedules by providing response-independent food on a variable-

time (VT) schedule, food delivery being dependent upon the absence of responding following FI reinforcement; a different key-colour was correlated with the VT schedule. Using this procedure, Shull and Guilkey found that the duration of the postreinforcement pause on the FI schedule was unaffected by the delivery of response independent food (see also Buchman and Zeiler, 1975). As was the case in the present experiments, long postreinforcement pauses failed to occur despite the increase in reinforcement rate that this would have produced. Further, as the present experiments indicate, changes in mean interreinforcement interval do not directly affect post-reinforcement pause duration (cf. Shull 1978).

The natural rate hypothesis

On schedules where reinforcement opportunity is spaced in time, e.g. on FI and IRT>t schedules, most organisms emit considerably more responses than required for reinforcement. Indeed, on IRT>t schedules excessive responding occurs despite the fact that it results in loss of reinforcements. Pigeons are notable for their inability to with-hold their key-pecks on IRT>t schedules (Harzem, 1969; Kramer and Rilling, 1970; Reynolds, 1966). Moreover, under this schedule response-bursts, i.e. two or more responses occurring in very rapid succession, are observed even though such bursts are never reinforced. To account for these phenomena Staddon (1972) (a), 1975 (a)) has suggested that there is a natural response rate for a given species and response topography, and that when an organism is required to respond at a low rate, it at times responds rapidly in order to bring up the response rate to its natural level. On the basis of this

hypothesis it would be expected that in the alt FI IRT>t schedules a pause long enough to meet the IRT>t criterion would be more likely to occur following an FI response run than following an IRT>t pause (cf. Staddon, 1975(a)). No such relationship was observed, however, in the present experiments. Moreover, taking only the pauses that followed FI runs, such pauses were not related to the number of responses that occurred in the preceding FI run. Also, Ferraro, Schoenfeld and Snapper (1965) have reported that on IRT>t schedules an IRT long enough for reinforcement is more probable following a similarly long IRT than following a short, unreinforced IRT (see also Harzem, Lowe and Davey 1975(b)). It would appear, therefore, that characteristics of performance on temporally based schedules cannot be accounted for by reference to natural response rates.

Conclusion

Ferster and Skinner (1957) have suggested that on FI schedules reinforcement functions as a discriminative stimulus setting the occasion for a period without responding (cf. Skinner, 1938; Dews, 1970). This kind of discriminative control is also observed on IRT>t schedules (Harzem, Lowe and Davey, 1975(b)), and with stimuli other than reinforcer (Davey, Harzem and Lowe, 1975; Zeiler, 1972). The present experiments provided further evidence of such control, and evidence as to the determination of the duration of the period of not responding. It appears that the duration of a postreinforcement pause is related to the contingencies operating at that time, signalled by the particular reinforcer that initiated the pause. Where more than

one temporal contingency is in operation, the pause is not the result of some averaging process; the contingency controlling the shortest pause prevails.

The simple IRT>t schedules run in the present experiments produced results in accordance with findings reported by other experimenters investigating such schedules (cf. Catania 1970). The postreinforcement pauses were of greater duration than the schedule parameter at short IRT>t values and of shorter duration at longer IRT>t values.

Thus, the relationship is best described by a power function with an exponent of less than one. Such a relationship is linear when plotted on double logarithmic co-ordinates.

However, the simple FI schedules run produced results similar to those found with the simple IRT>t schedules. The relationship between the postreinforcement pause and the FI value appeared to be linear on double logarithmic co-ordinates. Figure 12 also appears to indicate that the gradient of the line may be less than one. Findings such as these are contrary to reports in the literature which suggest that the postreinforcement pause increases linearly with FI duration and is a constant proportion of the FI duration (Dukich and Lee 1973; Sherman 1959; Shull 1971(b)). The discrepancy between these reports and data obtained from other temporally-defined schedules was noted in chapter three. The next chapter therefore investigates the relationship between postreinforcement pause and FI duration and attempts to reconcile these apparently contradictory findings.

CHAPTER SEVEN

THE POSTREINFORCEMENT PAUSE AND THE POWER LAW ON

FIXED-INTERVAL SCHEDULES

One of the most frequently cited findings in the literature

on the experimental analysis of behaviour is that the duration of

the postreinforcement pause on FI schedules is a linear function of

schedule value; the pause occupying a constant proportion of the

interval regardless of interval duration (e.g. Dukich and Lee 1973;

Gibbon 1977); Lowe, Davey and Harzem 1974; Nevin 1973; Sherman

1959; Shull 1971b; 1978; Shull and Guilkey 1976; Starr and

Staddon 1974). This relationship is represented by the equation;

$$Y = cX+K$$

Where Y is the duration of the postreinforcement pause, X is

the FI value, c is the gradient of the line and K is the intercept

on the postreinforcement pause axis, the intercept being Zero.

A number of authors have suggested that the occurrence of a
long postreinforcement pause provides evidence for temporal
discrimination on FI schedules (e.g. Mackintosh 1974; Stubbs 1978;
Zeiler 1977) and theories of temporal control have often assumed
a proportional relationship between postreinforcement pause and FI
duration, e.g. the scalar expectancy theory of Gibbon (1977) and
the natural rate hypothesis of Staddon (1972a; 1975a). The propor-
tionality assumption has also been incorporated in accounts of temporal
control by Shull (1978) and Nevin (1973).

There are both theoretical and empirical grounds, however, for
doubting the validity of this finding. There is now considerable
evidence from both animal and human studies that, under a variety of
experimental conditions, the relationship between responding and
temporal properties of the environment is not a linear one but is
best described by a power function with an exponent of less than one.
This has been shown to be the case in animal experiments involving IRT
and response latency (Catania 1970), response durations (Kuch 1974;
Platt, Kuch and Bitgood 1973), time taken to complete a fixed ratio
(De Casper and Zeiler 1974) pause and run times on FR schedules (De
Casper and Zeiler 1977) and interchangeover time on concurrent
schedules (Stubbs, Pliskoff, and Reid 1977), Catania (1970) has also
shown that a power function describes the relationship between response
and stimulus durations in several experiments concerned with temporal
judgments in human subjects (see also Eisler 1976, and Platt 1978).
Given the generality of the power law across different temporal

differentiation studies, it is surprising that the postreinforcement
pause on FI schedules does not conform to this law, but instead
obeys a simple linear function when related to schedule parameter.

The evidence which has been presented to show a proportional
relationship comes from remarkably few studies and, upon close
examination, appears to be less than conclusive. For example, of
those studies which have reported that postreinforcement pause increased
as a constant proportion of schedule value, Sherman (1959) employed
a between-groups design with only two rats in each group; Shull (1971b)
used two pigeons in a within-subjects design, one bird being trained
on two and the other on three FI values; Dukich and Lee (1973) also
used only three FI values, these being introduced in ascending order
for each rat. The study perhaps most often cited as evidence for a
linear relationship between postreinforcement pause and FI value
(see, for example, Shull 1971b; Shull and Guilkey 1976; Staddon 1972a;
1975a) is that of Schneider (1969), who did not, however, report any
postreinforcement pause data, believing that the first response
after reinforcement occurred in a "seemingly random fashion". Several
authors appear to have confused the "breakpoint" measure, which
Schneider did record and show to be a linear function of FI value,
with postreinforcement pause duration, which was not recorded or
reported.

EXPERIMENT 4

METHOD

A detailed description of the apparatus and procedure is given
in chapter six (cf. Harzem, Lowe and Spencer, 1978), which also

briefly reports some results from this experiment. The subjects
were four male hooded rats; all had histories of responding on
FI and IRT>t schedules. The prefixes to the animal numbers are
denoted as R in the present chapter rather than P to differentiate
between this rat study and other, to be reported, pigeon experiments.
Six different FI values, ranging from 15 to 480 sec., and three
redetermination values were presented in random order, schedule
parameter being altered when responding became stable. The reinforcer
was a 45 mg. Noyes pellet throughout.

RESULTS AND DISCUSSION

Figure 15 shows for individual animals the duration of the
postreinforcement pause (filled circles) and the relative postrein-
forcement pause i.e. pause expressed as a proportion of the FI value
(open circles) as functions of FI value. (For measures of variability
of pause duration, see Table 4. The absolute duration of postrein-
forcement pause increased as a positive function of schedule,
parameter, this increase being negatively accelerated for all subjects.
The relative pause declined with increasing FI value. The data show
that the duration of the pause was not a constant fraction of the value
of the FI schedule in operation, a finding which is not in agreement
with earlier studies of FI performance in rats which have reported
the proportional relationship (e.g. Sherman, 1959; Dukich and Lee,
1973). However, methodological differences between these latter
studies and the present experiment preclude close comparison.
Sherman (1959), in an unpublished study, used a between-groups design,

Figure 15. Experiment 4: Mean duration of absolute
postreinforcement pause (filled circles) and relative
postreinforcement pauses i.e. postreinforcement pause
as a proportion of FI schedule value. Unconnected
points indicate redetermination values. Data are
for individual animals from the last three sessions
on each schedule value.
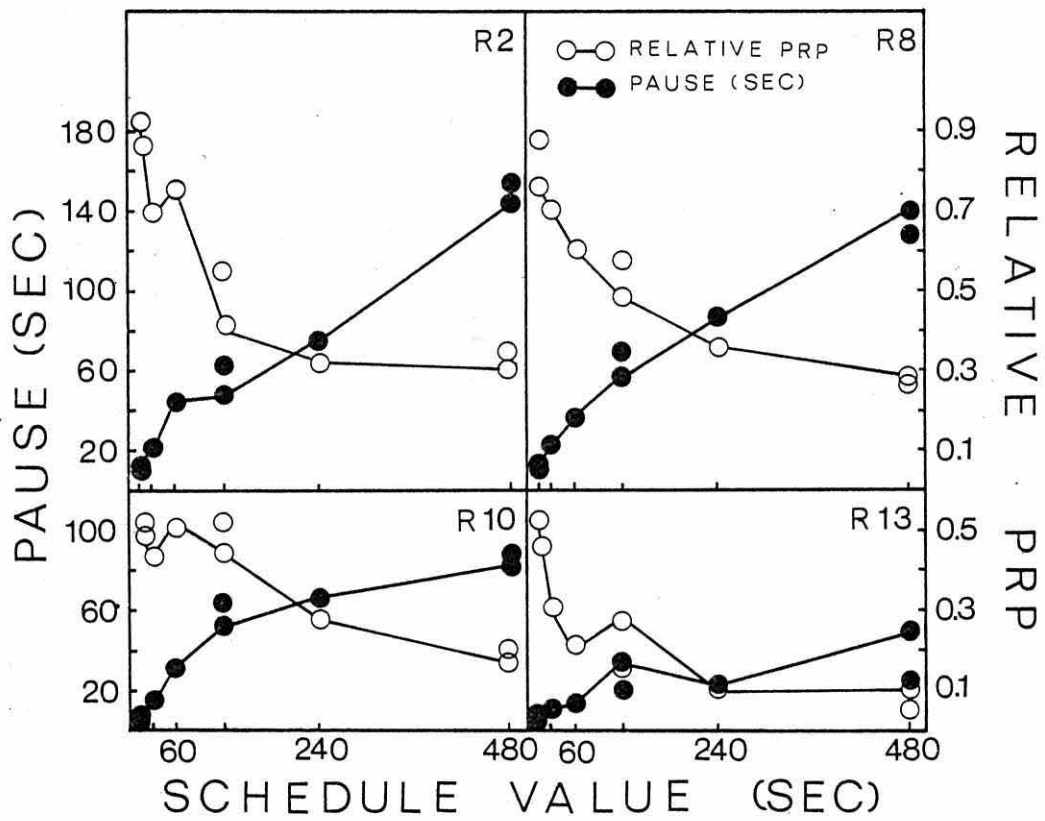
where each group of rats was assigned to one of five FI values;
a "group" consisted of two animals. Dukich and Lee (1973) also
using rats as subjects, employed a within-subjects design and three
different FI values 30, 60 and 120 sec; unlike the present
experiment where the order of presentation of the schedule values
was randomized and redetermination points were established, the FI
values were presented in ascending order for each animal. This
latter procedure, providing as it does a longer FI history prior
to performance on the higher FI values, does not allow for an
independent assessment of the effect of the FI parameter on perform-
ance.

Overall response rate and running rate (i.e., response rate
calculated by excluding the postreinforcement pause) on each FI value
are presented in Figure 16. This shows a negatively accelerated
decline in running rate as a function of increasing schedule parameter
for all subjects. Overall response rate also decreased with increasing
FI value, the degree of change being less marked than in the case of
running rate. Similar overall rate functions have been reported in
earlier studies of FI performance in rats (Skinner 1938; Wilson 1954).

EXPERIMENT 5

While Experiment 4 showed that the postreinforcement pause of
rats on FI schedules increased as a negatively accelerated, rather
than linear, function of FI value there remains the possibility that
a linear relationship accurately describes the performance of other
species on FI schedules. For example, Lowe and Harzem (1977) have

Figure 16. Experiment 4: Mean running rates and
overall rates as functions of FI value. Unconnected
points indicate redetermination values. Data are from
the last three sessions on each schedule value.

RESPONSES PER MINUTE

RUNNING RATE

R2 R8 R10 R13

OVERALL RATE

R2 R8 R10 R13

SCHEDULE VALUE (SEC)
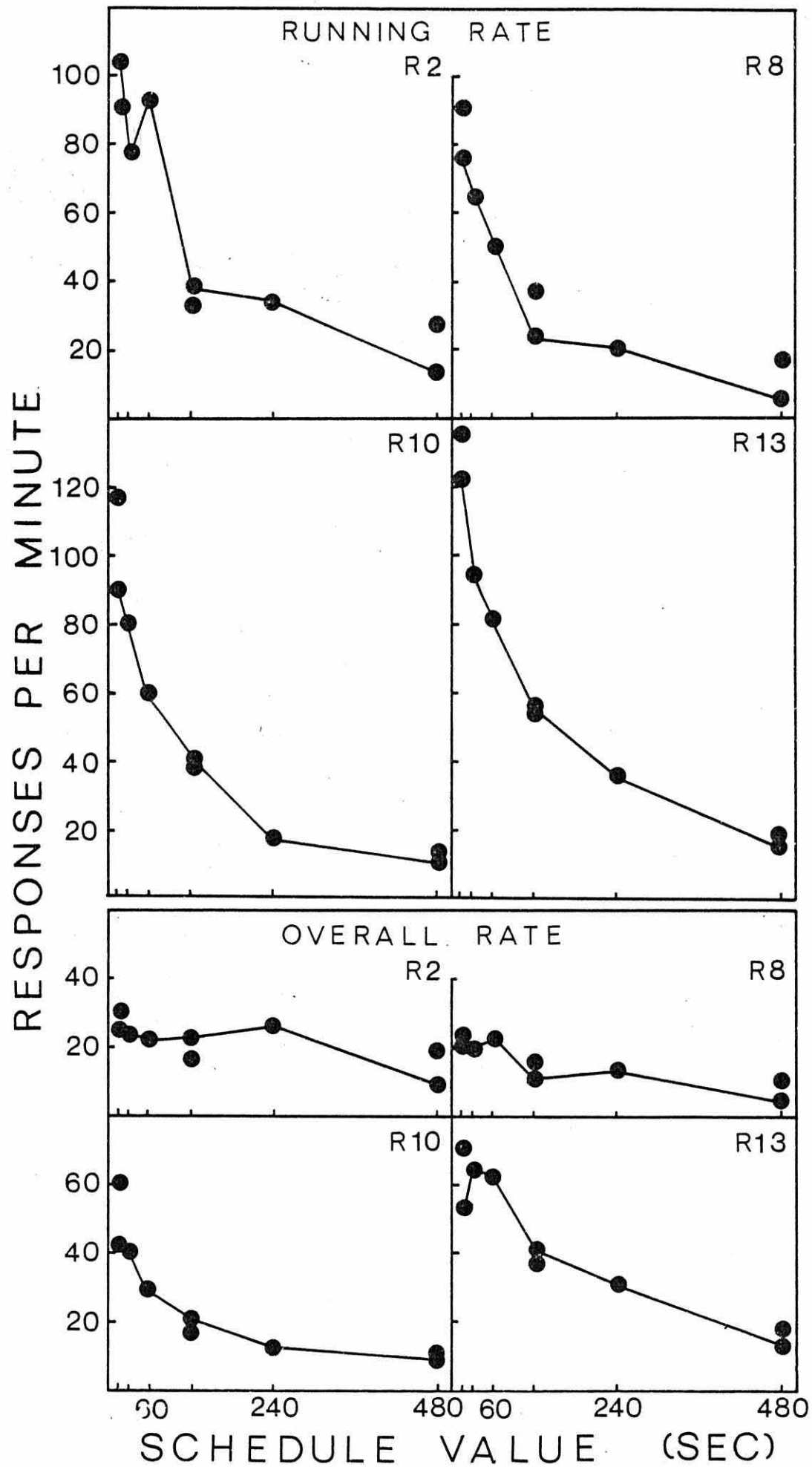
shown that there are differences between rats and pigeons in temporal
control of behaviour and Shull (1971b) has presented evidence
suggesting that in pigeons postreinforcement pause increases as a
constant proportion of FI value. The present experiment investigated
the relationship between pause and FI parameter in pigeons. Previous
investigations of the FI parameter have kept the reinforcer constant
while altering FI value, a procedure which was also adopted in the
present experiment; in addition, a second procedure was employed
where the duration of the reinforcer was maintained as a constant
proportion of the value of the fixed interval. These two procedures
(i) provided a test for the possibility that a proportional relation-
ship between pause and interval value would be more readily obtained
when there is also a proportional relationship between reinforcer
duration and interval value and (ii) allowed for possible motivational
deficiencies of a small reinforcer when very long F.I. values were
being used.

<center>METHOD</center>

Subjects

Four mixed breed pigeons were used, all approximately two years
old at the start of the experiment. The animals were housed
individually, with water and grit freely available in the home cages,
and were maintained at approximately 80% of their free-feeding
weights by controlled feeding at the end of the day. They had a
previous history of performance on an FI 60-sec schedule.

Apparatus

Two Lehigh Valley model 141-16 chambers were used, with the
centre key illuminated. During the reinforcement cycle, the keylight

Table 5

Number of sessions and interquartile ranges of postreinforcement pauses (sec) in each condition of Experiment 5. The order of schedule values is shown from top to bottom.

Animals	FI (sec)	Rft. duration (sec)	No. sessions	Interquartile ranges of pauses	Animals	FI (sec)	Rft. duration (sec)	No. sessions	Interquartile ranges of Pauses
1SG	15	1.5	18	6.9 - 10.5	3SG	120	3.0	21	29.5- 56.1
	480	48.0	23	96.1 - 169.2		15	3.0	9	7.2- 13.1
	120	12.0	15	29.1 - 40.3		480	3.0	52	39.8- 119.2
	60	6.0	14	23.2 - 40.2		60	3.0	15	11.4- 25.3
	60	3.0	17	18.3 - 39.1		60	6.0	16	11.4- 23.2
	480	3.0	42	60.2 - 126.3		120	12.0	12	26.1- 48.4
	15	3.0	8	5.6 - 9.9		480	48.0	26	67.0- 153.2
	120	3.0	10	18.1 - 53.2		15	1.5	12	4.9- 8.3
	240	3.0	24	20.2 - 60.6		240	24.0	19	26.8- 57.9
	240	24.0	26	35.2 - 62.4		240	3.0	30	22.1- 55.5
2SG	15	1.5	18	4.7 - 9.2	15C	120	3.0	21	21.4- 61.2
	480	48.0	21	60.3 - 170.7		15	3.0	9	5.8- 11.2
	120	12.0	15	17.0 - 42.3		480	3.0	56	49.7- 102.2
	60	6.0	12	14.1 - 22.2		60	3.0	15	11.1- 24.5
	60	3.0	17	12.1 - 27.6		60	6.0	16	10.8- 26.9
	480	3.0	37	22.6 - 102.6		120	12.0	12	28.1- 54.3
	15	3.0	9	3.1 - 4.9		480	48.0	24	88.9- 209.6
	120	3.0	10	11.1 - 16.7		15	1.5	12	3.9- 5.0
	240	3.0	22	19.6 - 50.4		240	24.0	20	43.2- 78.7
	240	24.0	25	22.7 - 66.4		240	3.0	28	23.9- 53.9

was extinguished, and the hopper was illuminated. The houselight remained on throughout the experiment. Masking sound was provided by fans. The reinforcer was a specified duration of access to grain. Each new interval began when the food hopper was lowered, and ended when it was raised. A Nova 1200 computer was employed for experimental programming and recording of data.

Procedure

Five FI values, ranging from 15 to 480 sec., were used. The birds performed under each of two reinforcement conditions: (i) Constant Reinforcer, where the duration of access to grain at the end of the fixed interval was 3 sec and (ii) Variable Reinforcer, where duration of access to grain was $\frac{1}{10th}$ of the duration of the FI value. Each change in schedule or reinforcer duration was made when inspection of the cumulative records indicated that responding was stable and when the following stability criteria were met: (i) variation in the mean duration of postreinforcement pauses in 5 successive sessions less than 10% of the mean duration for all five sessions; and (ii) variation between response rates in each of the 5 sessions less than 10% of the mean rate for all 5 sessions. Sessions lasted 100 mins or until 12 min access to grain had been given, whichever occurred first. Table 5 shows the sequence of experimental conditions for each subject and the number of sessions on each condition.

RESULTS AND DISCUSSION

The left panel of Figure 17 shows for individual subjects duration of postreinforcement pause as a function of FI value in the constant reinforcer (filled circles) and in the variable reinforcer (open circles) conditions; the interquartile ranges of these durations are given in Table 5. When the duration of the reinforcer remained constant pause increased as a negatively accelerating function of schedule value. The pause following the variable reinforcer was longer than that following the constant reinforcer only on the higher FI values, when the difference between the variable duration and that of the constant was considerable. Relative postreinforcement pause data are presented in the right panel, which shows that when the reinforcer duration remained constant the relative pause declined as a function of increasing interval value; this was also true of relative pause in the variable condition with the possible exception of Bird 15C. The evidence from both the constant and variable reinforcer conditions accords well with that of Experiment 4, showing that in pigeons, as with rats, the duration of postreinforcement pause does not increase as a simple proportion of the FI duration but is a negatively accelerated increasing function of FI value.

The postreinforcement pause data of the present experiment are not in agreement with those of Shull (1971b), who, using pigeons as subjects, reported a proportional relationship between pause and FI value. Shull's functions, however, were based upon only two FI values in the case of one subject and three values in the case of a second, two subjects being used in all. On the other hand, the pause/interval

Figure 17. Experiment 5: Postreinforcement pause data
from the constant reinforcer (c) conditions (filled
circles) and the variable reinforcer (v) conditions
(open circles) as functions of schedule value. Mean
duration of postreinforcement pause is shown in left
panels and relative pause in right panels. Data are
from the last three sessions on each schedule value.
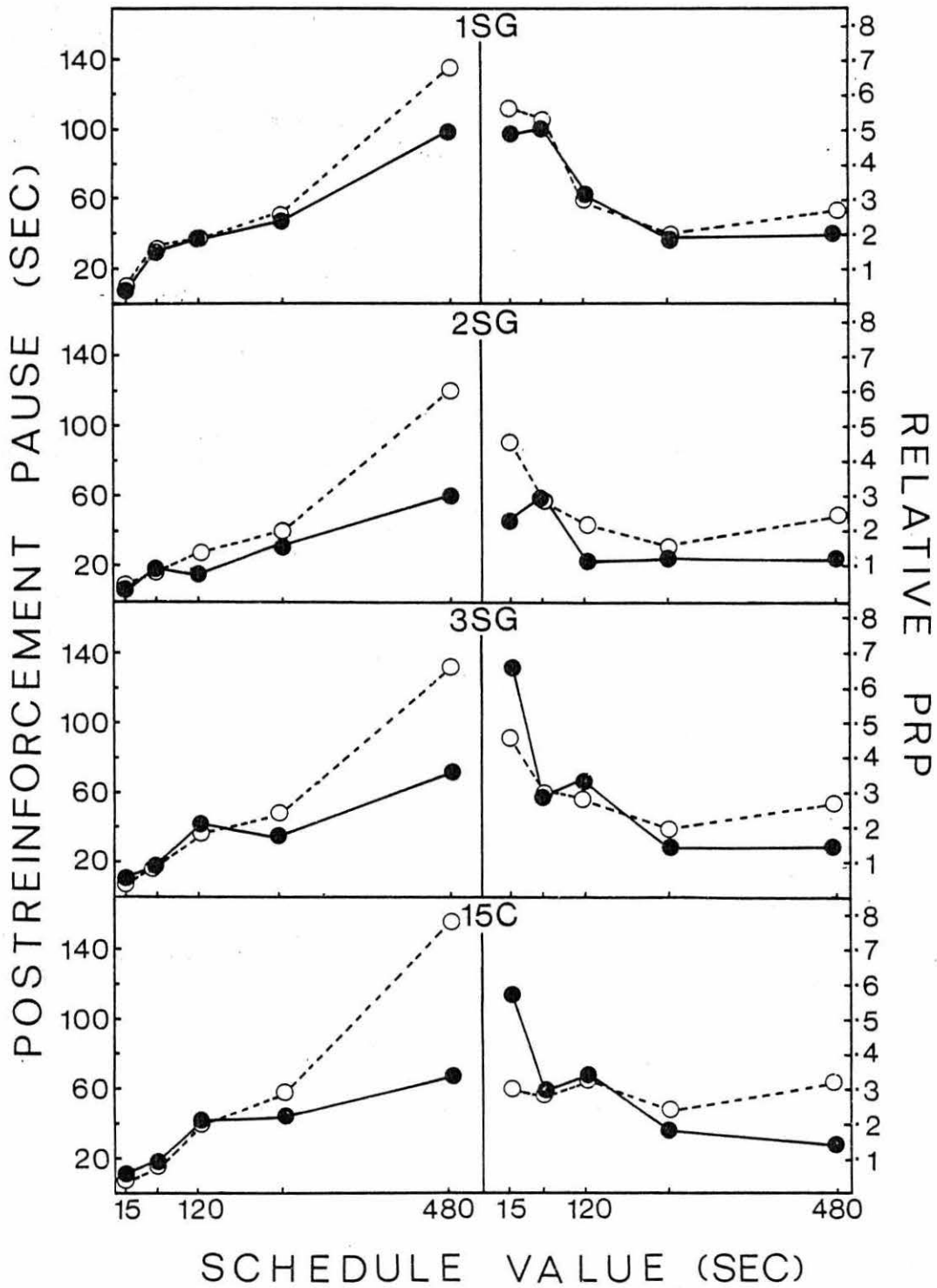
functions observed in this experiment closely resemble those reported
by Innis and Staddon (1971) for pigeon's performance on cyclic-
interval schedules. The relationship between pause and FI parameter
will be further discussed in a later section.

The inhibitory after-effects of reinforcement magnitude observed
in the present experiment have also not been reported previously.
While several authors found that increasing the magnitude of the rein-
forcer on an FI schedule results in longer postreinforcement pauses
(e.g. Lowe Davey and Harzem 1974; Davey, Harzem and Lowe, 1975;
Staddon, 1970a), these studies have contrasted the different magnitudes
closely in time, i.e., within a session; when behaviour has been
stabilised on each magnitude separately, no differential effects on
pausing have been observed (Harzem, Lowe and Davey, 1975a; Hatten and
Shull, 1972; Jensen and Fallon, 1973). The present experiment, however,
showed effects of reinforcer duration on pause when performance was
stable on each magnitude but only when the differences between rein-
forcers was great and reinforcer durations as long as 24 and 48 sec
were used; when reinforcer durations of 12 sec or less were compared
no magnitude effects were present. These findings are in agreement
with those of Hatten and Shull who failed to find any effect of rein-
forcer magnitude on stable FI performance in pigeons when different
reinforcer durations of up to 8 sec were presented and suggest that
inhibitory effects of reinforcer magnitude will only be observed in
stable FI performance when there are large differences in reinforcers.

Figure 18 shows running rate and overall rate data for each
subject in the constant (filled circles) and variable (open circles)

Figure 18. Experiment 5: Mean running rates and
overall rates as functions of FI value for the
constant reinforcer conditions (filled circles) and
the variable reinforcer conditions (open circles). Data
are from the last three sessions on each schedule value.
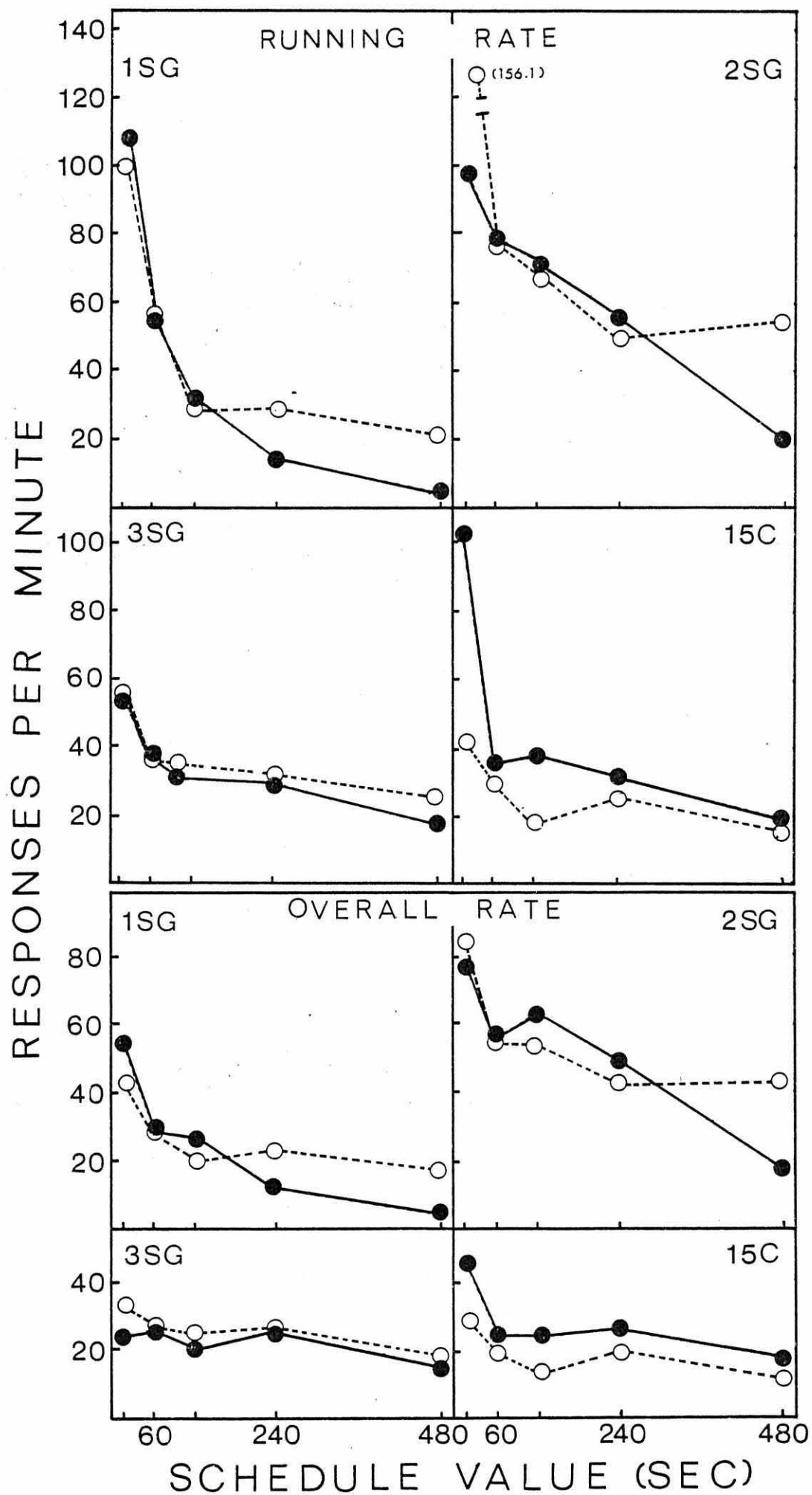
conditions. Running rate declined as a negatively accelerated function of schedule value for all subjects in both conditions; in three of the four birds, 15C being the exception, running rate was higher with the variable reinforcer duration but only on the higher FI values when the duration of the variable reinforcer was considerably longer than that of the constant reinforcer. Similar effects were present in the overall rate data, which show that although longer pauses occurred following the longer (variable) reinforcer on high FI values, overall response rate was still higher in the variable than in the constant reinforcer condition. These data thus point to a motivational effect of increased reinforcer magnitude on response rate, longer reinforcer durations resulting in higher response rates. Although similar rate enhancing effects of reinforcer magnitude have been reported for rat performance on FI schedules (e.g. Guttman, 1953; Jensen and Fallon, 1973; Mettzer and Brahlek, 1968, 1970; Stebbins, Mead and Martin 1959), such effects have not been previously reported in pigeons (Keesey and Kling, 1961; cf. Lowe Davey and Harzem 1974). It seems likely that the success of the present experiment in yielding magnitude of reinforcement effects on response rates was due to a wider range of reinforcer magnitudes than employed previously (cf. Keesey and Kling, 1961).

Schneider (1969) showed that time from breakpoint to reinforcement varied in the course of a session (cf Shull 1971(b)). Schneider suggested that the animal could be viewed in effect as being on a VI schedule once responding had commenced. From this, it would be expected that the rate of response in this 'second state' would bear the same relation-

ship to reinforcement rate in this second state as does overall
response rate on VI schedules to overall reinforcement rate on VI
schedules (cf. Herrnstein 1961; 1970). The reinforcement rate in
the FI second state is found by calculating the mean time in minutes
from the first response to reinforcement, and then taking the
reciprocal of this number. Thus if the mean time from the first
response in the interval to reinforcement is 2 minutes the reinforcement
rate in the second state would be $\frac{1}{2}$ - 0.5 reinforcement per minute.
The rate of response in the second state is the FI running rate. Rate
of responding on VI schedules is related to reinforcement rate by the
equation:

$$R_A = R_{MAX}(\frac{r\ A}{K_{H+r}\ A})$$, which defines a rectangular hyperbola

R_A = response rate, r_A = reinforcement frequency

R_{MAX} is a constant and refers to the maximum response rate.

K_H is a constant which refers to the reinforcement frequency corresponding
to the half-maximal response rate (cf. Bradshaw, Szabadi and Bevan
1976).

The reinforcement frequency of the second state of the rat FI
data and the pigeon FI data under both constant and variable reinforcer
conditions was calculated and related to response rate in the second
state (FI running rate) by the rectangular hyperbole of best fit.
Figure 19 shows that the rat and pigeon data from the constant rein-
forcement duration (c) condition show very good fits, compared with
the VI data of Catania and Reynolds (1968) fit by de Villiers and
Herrnstein (1976), though the pigeon data are somewhat erratic where
the reinforcement duration was variable (v). Figure 20 shows the group

Figure 19. Experiments 4 and 5: Response rate in
the second state as a function of reinforcement rate
in the FI second state for rats (left panels),
pigeons in the constant reinforcer (c) conditions
(centre panels), and pigeons in the variable rein-
forcer (v) conditions (right panels). The curves are
the rectangular hyperbole of best fit. For each
animal the constants R_{MAX} and K_H and the coefficient
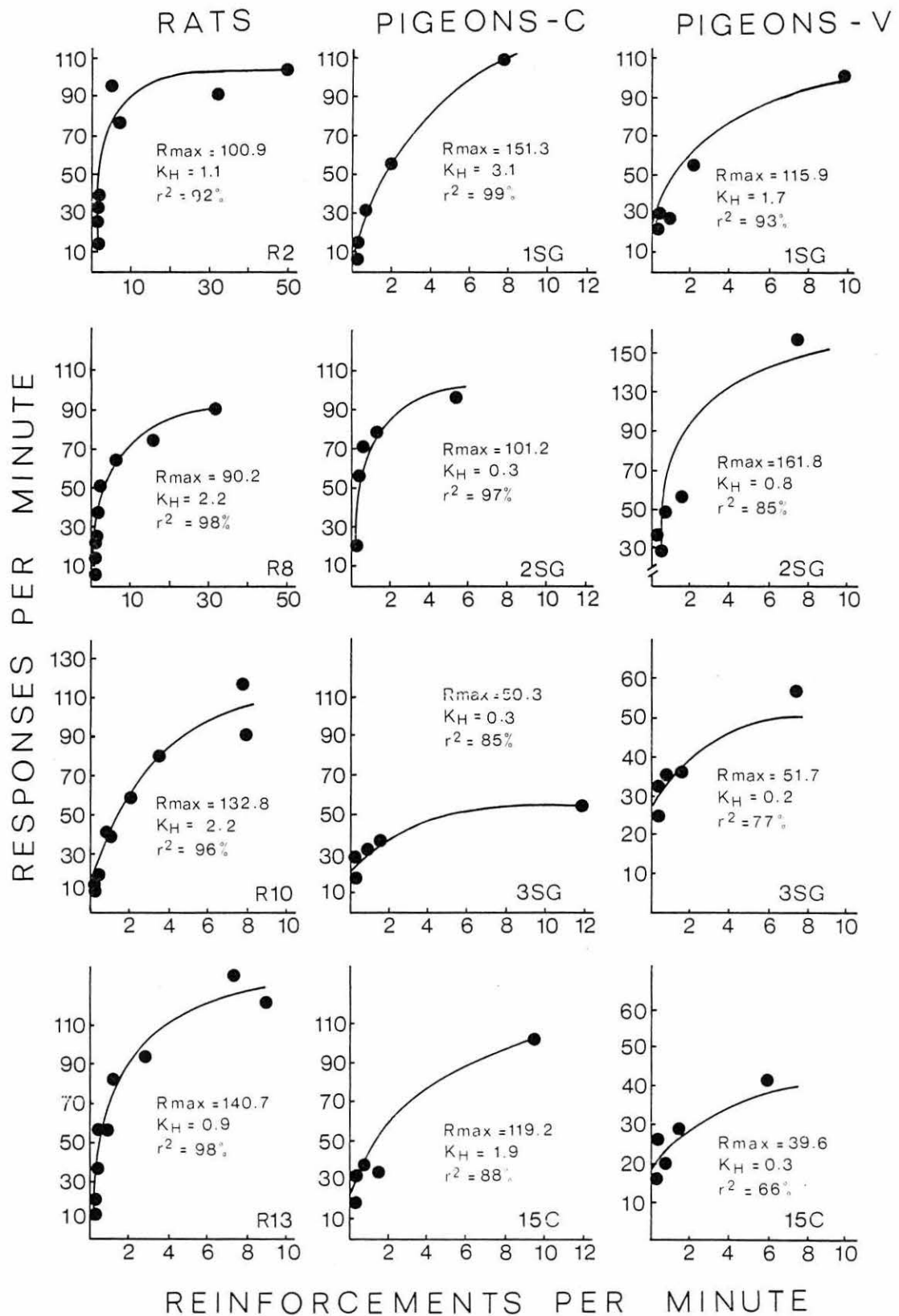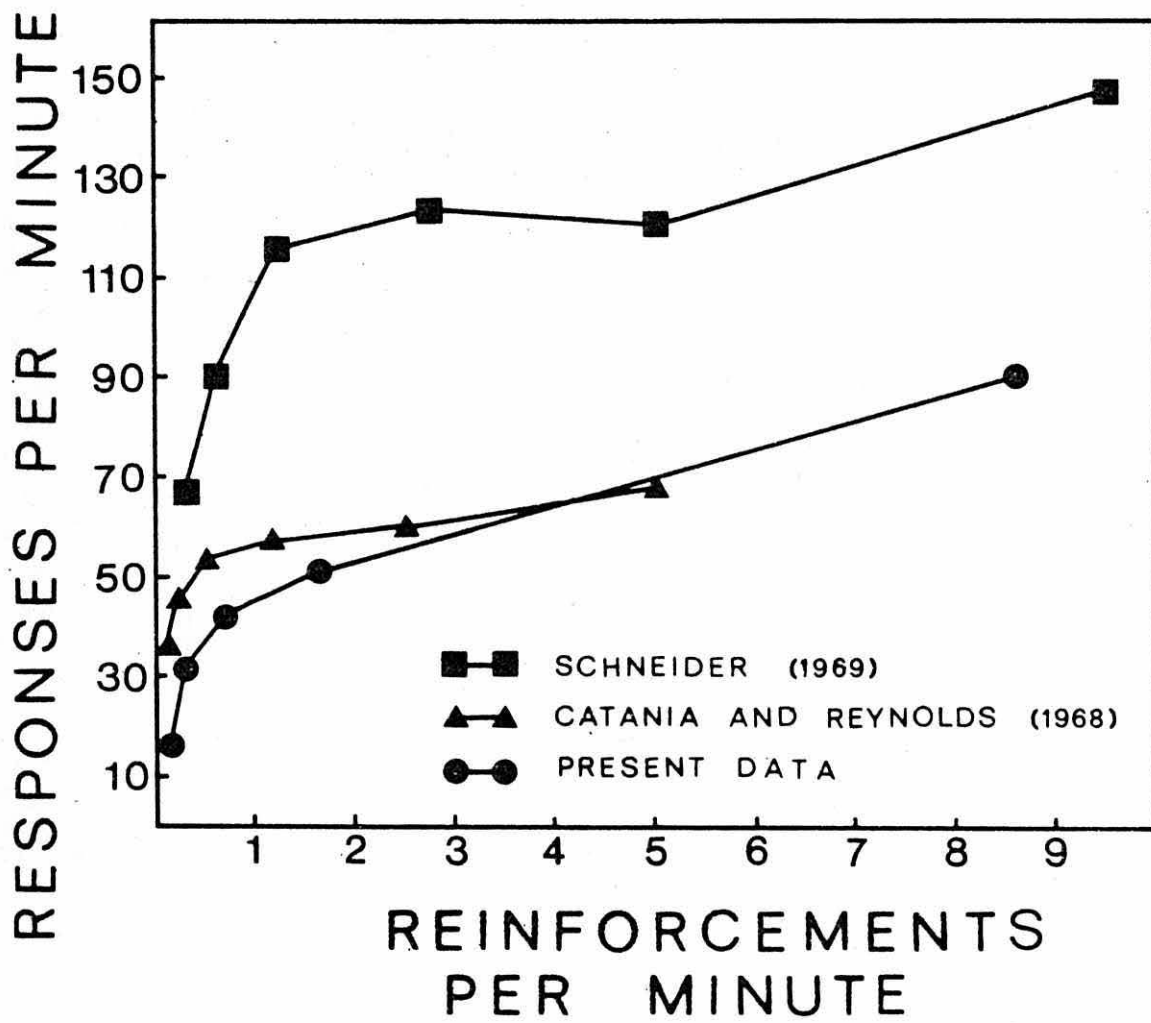of determination (r^2) are given.

Figure 20. Response rate in the FI second state as
a function of reinforcement rate in the second state
for the data of Schneider (1969) and the constant
reinforcer duration conditions in Experiment 5. The
VI data of Catania and Reynolds (1968) is also given.
The curves represent group means.

mean data from the FI second state of the pigeons in the present
experiment under the constant reinforcer conditions compared with
the VI pigeon data of Catania and Reynolds (1968) and the rate after
breakpoint data of Schneider (1969), again with pigeons. As can be
seen, the Schneider data shows a considerably higher rate for a
given reinforcement frequency as compared to that of Catania and Reynolds,
a fact noted by de Villiers and Herrnstein (1969). However, the data
from the present experiment using rate after pause, shows a close
relationship with that of Catania and Reynolds.

EXPERIMENT 6

In Experiment 5 it was shown that when different reinforcer
durations were presented on FI schedules, performance being
stablilised on each reinforcer, both postreinforcement pause and
response rate increased with the longer reinforcers. Previous studies
have shown similar effects on postreinforcement pause when different
reinforcer magnitudes were contrasted within experimental sessions
(cf. Lowe Davey and Harzem 1974; Staddon, 1970a). The present
experiment was conducted to compare the effects of reinforcer duration
when different durations were contrasted in each session (contrasted
condition) and when performance was stabilised on each reinforcer
(single condition).

METHOD

Subjects and Apparatus

The same subjects and apparatus were used as in Experiment 5.
After Experiment 5 the birds were placed on free-feeding for some time

TABLE 6

Number of sessions and interquartile ranges of postreinforcement pauses in each condition of Experiment 6. Data from the contrasted reinforcer condition is shown for successive blocks of three sessions. The order of conditions is shown from top to bottom. BL_1 = first baseline condition. BL_2 = second baseline condition.

| Rft. duration (sec) | ANIMALS | | | | Rft. duration (sec) | ANIMALS | | | |
| | 1SG | | 2SG | | | 3SG | | 15C | |
	No. sessions	Pause (sec)	No. sessions	Pause (sec)		No. sessions	Pause (sec)	No. sessions	Pause (sec)
(BL_1) 3	25	47.6- 97.0	25	18.5- 49.0	(BL_1) 24	25	38.0- 98.5	25	53.0-104.5
(BL_1) 24	26	62.5-100.0	26	36.8- 86.5	(BL_1) 3	26	24.0- 60.0	26	32.7- 73.5
3] 24]	3	23.0- 55.2 44.2- 96.5	3	7.0- 58.0 56.3-122.1	3] 24]	3	40.2- 68.5 78.0-134.0	3	17.0- 39.0 49.0-120.0
3] 24]	3	23.6- 60.1 50.1-103.6	3	8.9- 60.0 55.1-118.6	3] 24]	3	10.3- 28.6 36.0- 92.6	3	20.1- 44.1 53.4-110.2
3] 24]	3	22.8- 71.2 60.3-116.2	3	9.7- 61.7 54.1-124.7	3] 24]	3	28.9- 57.9 71.0-125.3	3	29.7- 69.6 59.9-134.1
3] 24]	3	36.2- 87.5 82.3-137.9	3	27.9- 61.0 61.5-129.2	3] 24]	3	22.5- 48.6 78.5-122.1	3	24.0- 60.2 50.2-119.7
3] 24]	3	35.1- 56.5 73.0-145.0	3	12.0- 74.0 65.0-126.0	3] 24]	3	16.0- 37.0 39.2-122.7	3	12.0- 62.2 49.0-120.0
(BL_2) 3	28	40.0-114.2	28	33.5- 81.5	(BL_2) 24	28	46.2-110.7	28	42.0-122.2
(BL_2) 24	29	72.0-133.5	29	60.8-113.0	(BL_2) 3	29	26.5- 67.2	29	27.5- 77.0

and their 80% weights were redetermined for this experiment.

Procedure

An FI value of 240 sec. was used throughout. In the first
baseline condition two subjects were given 3 sec access to grain as
reinforcer and two subjects were given 24 sec; when performance had
stabilised reinforcer duration was changed to 24 sec for the former
subjects and to 3 sec for the latter, until performance was again
stable (see Table 6). In the fifteen subsequent sessions both 3-sec
and 24-sec reinforcer durations were presented randomly at the end
of each fixed interval. All subjects were then returned to the base-
line single reinforcer conditions, where the 3-sec and 24-sec rein-
forcers were each presented until performance was stable. The order
of conditions and the number of sessions on each condition is shown in
Table 6. The stability criteria and session length were the same as
in Experiment 5.

RESULTS AND DISCUSSION

Figure 21 shows postreinforcement pause following the 3-sec
(open circles) and 24-sec (filled circles) reinforcers; the data from
the contrasted reinforcer condition are presented for blocks of three
sessions (connected points). The interquartile ranges of these
durations are given in Table 6. When each reinforcer was presented
separately, in the baseline conditions, the pause of all subjects was
longer with the 24-sec than with the 3-sec reinforcer. This difference
was considerably enhanced when both reinforcers were contrasted within
sessions, in some subjects the change being mostly due to increase in

Figure 21. Experiment 6: Mean duration of post-
reinforcement pauses following the 3-sec reinforcer
(open circles) and following the 24-sec reinforcer
(filled circles). Data represent the last three
sessions of the baseline (BL) conditions (un-
connected points) and successive blocks of three
sessions from the contrasted reinforcer conditions
(connected points).
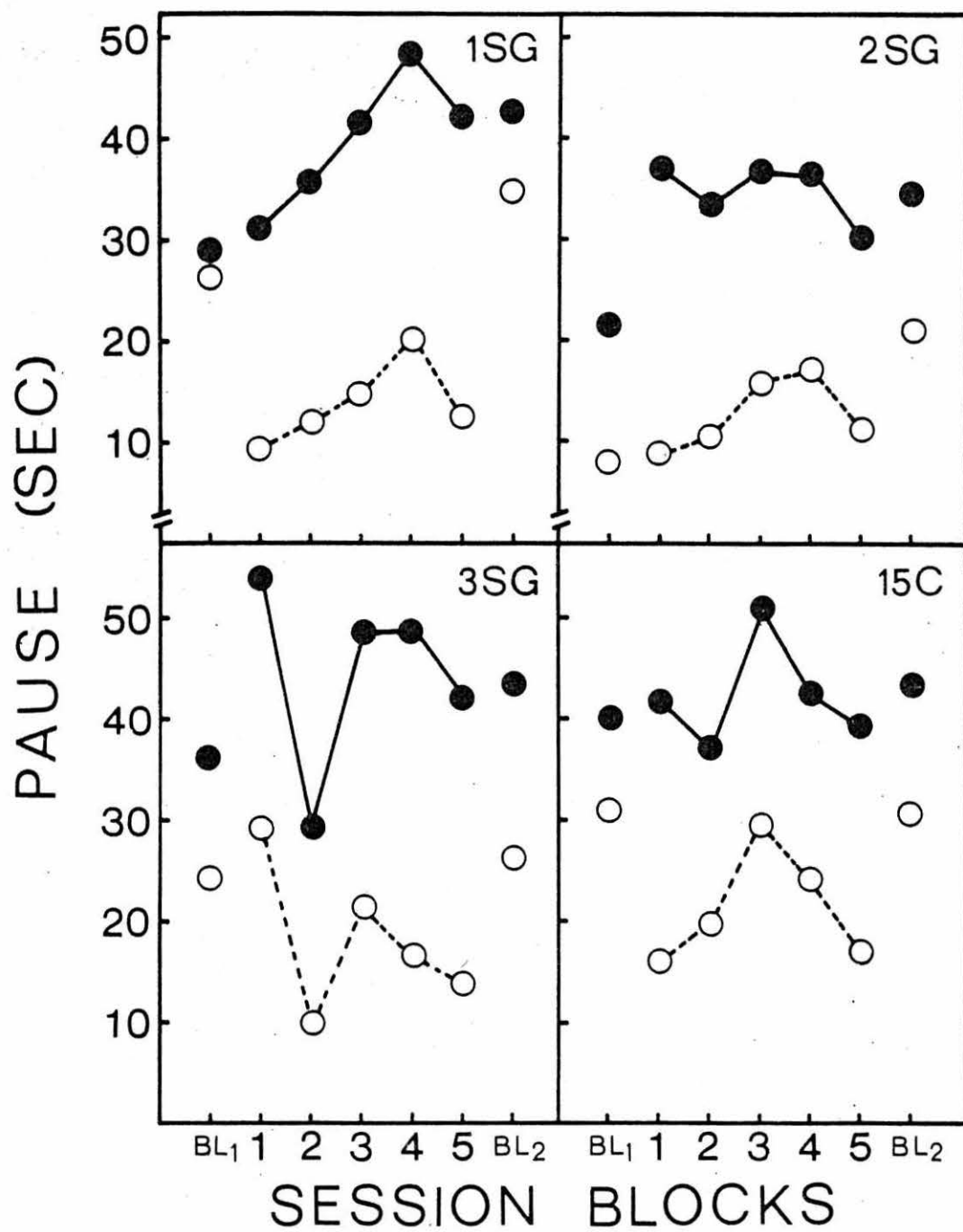
pausing following the 24-sec reinforcer while in others it was due to shorter pauses after the 3-sec reinforcer. The differences between the effects of the two reinforcers showed no signs of diminishing over the fifteen sessions of the contrasted condition (see also Staddon, 1970a). These results show that the degree of inhibitory after-effect of a reinforcer is dependent upon the context in which the reinforcer is delivered and may be enhanced or diminished given the presence within the same experimental session of another reinforcer of greater or lesser magnitude.

One possibility is that the difference in pause duration on the single and contrasted conditions is due to the motivational effects of the reinforcer (cf. Meltzer and Howerton 1973; 1975). In the single reinforcer condition each 24-sec reinforcer signalled the occurrence of a 24-sec reinforcer at the end of the interval while in the contrasted condition a 24-sec reinforcer could be followed by either a 3-sec or a 24-sec reinforcer; the constancy of the 24-sec reinforcer in the single condition could thus have resulted in higher response rates and shorter postreinforcement pauses. A similar argument holds for pauses following the 3-sec reinforcer; in the contrasted condition a 3-sec reinforcer could be followed by a 24-sec reinforcer thus resulting in shorter pauses and higher responses than in the single reinforcer condition.

Evidence in support of this account of motivational effects of the reinforcer is provided by the response rate data (Figure 22) which show that running rate following the 24-sec reinforcer was higher in the

Figure 22. Experiment 6: Mean and running rates and
overall rates following the 3-sec reinforcer (open
circles) and following the 24-sec reinforcer (filled
circles). Data represent the last three sessions of
the baseline (BL) conditions (unconnected points)
and successive blocks of three sessions from the
contrasted reinforcer conditions (connected points).

RESPONSES PER MINUTE

SESSION BLOCKS
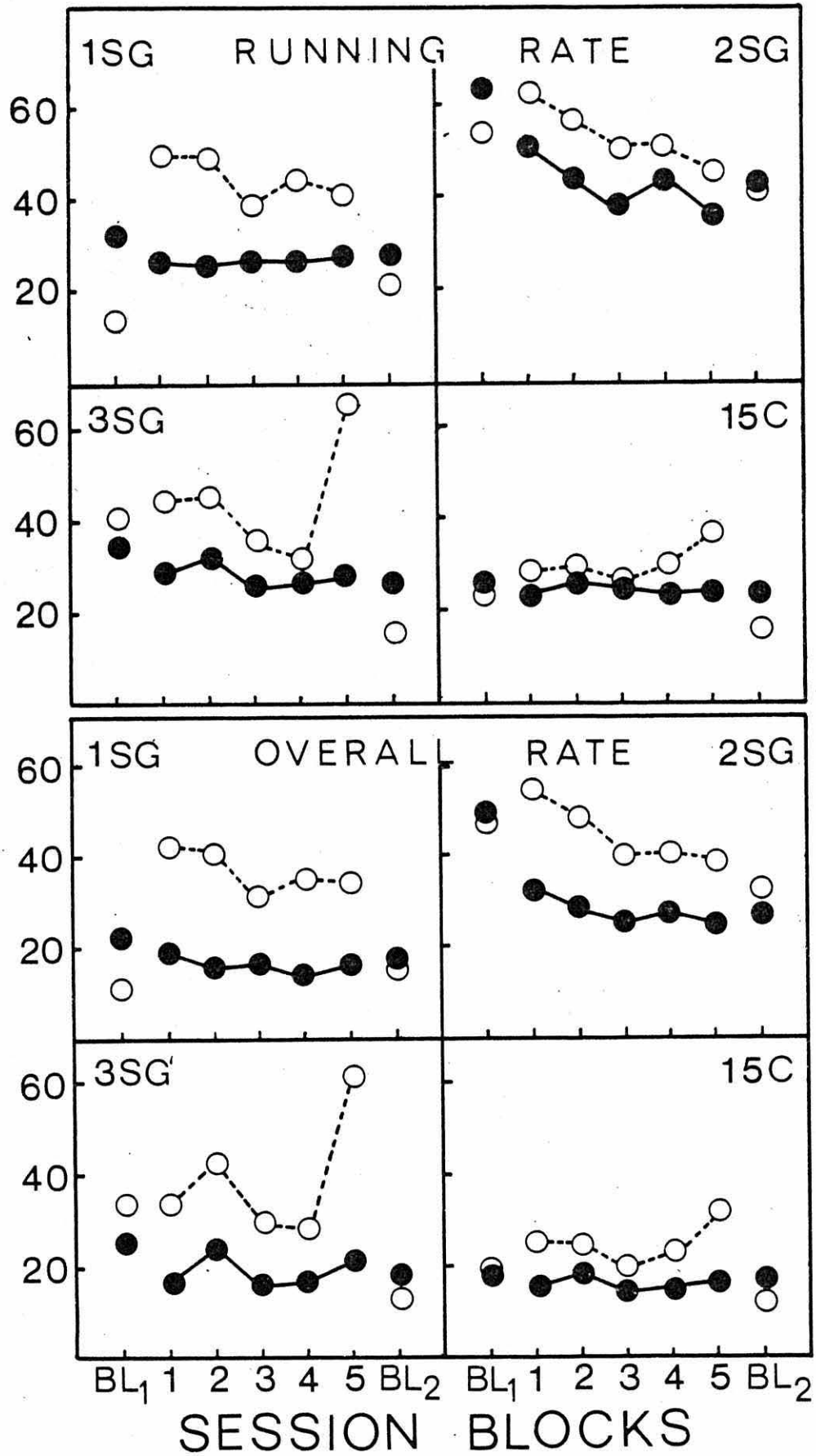
single than in the contrasted reinforcer condition. On the other hand, running rate following the 3-sec reinforcer was generally lower in the single than in the contrasted reinforcer condition.

Whereas running rates were often higher following the 24-sec than following the 3-sec reinforcer in the single reinforcer condition response rates were consistently lower following the longer reinforcer in the contrasted condition. These results are in agreement with those of Staddon (1970a), who also found an inverse relationship between reinforcer duration and subsequent running rate in pigeons but differ from results of experiments which have used rats as subjects. Lowe, Davey and Harzem (1974) found that the running rate of rats increased as a function of the magnitude of the preceding reinforcer when different reinforcers were used within the same session. This difference between rats and pigeons of the effect of prior reinforcer magnitude on subsequent running rate may be related to the different sensitivity of the leverpress in rats and the key-peck in pigeons to temporal control of response rate on FI schedules (cf. Lowe and Harzem 1977).

EXPERIMENT 7

Experiments 4 and 5 investigated the effect of the FI parameter on performance and in Experiment 6 the magnitude of the reinforcer was varied while FI value remained constant. In this experiment the after-effects of reinforcement magnitude were considered in relation to changes in the schedule parameter.

Table 7

Number of sessions and interquartile ranges of postreinforcement pauses (sec) in each condition of Experiment 7. The order of conditions is shown from top to bottom. BL = Baseline condition.

Animals	FI (sec)	Rft. duration (sec)	No. sessions	Interquartile ranges of pauses	Animals	FI (sec)	Rft. duration (sec)	No. sessions	Interquartile ranges of pauses
	20(BL)	4	15	7.3- 12.5		320(BL)	4	23	40.2- 56.9
		2		4.9- 8.1			2		14.2- 23.9
		4		4.8- 8.7			4		23.2- 59.9
	20	8	3	6.2- 9.8		320	8	3	32.2- 76.7
		16		9.0- 10.3			16		14.2- 91.2
		32		5.9- 12.5			32		12.7- 92.5
	320(BL)	4	24	32.2- 59.9		20(BL)	4	10	9.7- 14.7
		2		26.9- 59.2			2		6.3- 11.4
1SG		4		32.1- 54.3	3SG		4		7.5- 9.9
	320	8	3	52.1- 98.6		20	8	3	6.2- 13.0
		16		40.8- 85.6			16		7.0- 18.0
		32		45.1- 77.6			32		5.1- 18.3
	80(BL)	4	12	15.7- 40.3		80(BL)	4	14	16.9- 26.6
		2		25.0- 32.1			2		10.2- 15.7
		4		21.8- 34.5			4		17.4- 27.1
	80	8	3	15.9- 37.0		80	8	3	16.0- 28.3
		16		30.9- 57.1			16		19.1- 30.7
		32		27.2- 61.7			32		11.8- 34.6
	20(BL)	4	15	4.6- 8.5		320(BL)	4	23	22.5- 56.1
		2		4.2- 6.3			2		21.9- 81.6
		4		3.6- 6.3			4		32.8- 52.1
	20	8	3	5.8- 10.8		320	8	3	55.0-112.1
		16		5.5- 8.4			16		59.0-132.3
		32		3.1- 6.5			32		76.3-110.5
	320(BL)	4	25	31.5- 82.3		20(BL)	4	11	6.3- 10.6
		2		8.9- 68.0			2		4.0- 7.7
2SG		4		17.0- 70.8	15C		4		6.1- 10.3
	320	8	3	30.4- 62.6		20	8	3	5.8- 9.8
		16		18.2- 101.9			16		5.6- 10.9
		32		19.5- 102.1			32		6.7- 15.5
	80(BL)	4	11	6.6- 16.4		80(BL)	4	13	10.2- 16.4
		2		10.0- 19.6			2		9.4- 15.8
		4		9.6- 22.3			4		9.3- 22.1
	80	8	3	8.2- 22.7		80	8	3	16.7- 26.0
		16		13.0- 25.5			16		9.9- 20.9
		32		9.4- 26.6			32		16.2- 27.7

METHOD

Subjects and Apparatus

The subjects and apparatus were the same as used in Experiments 5 and 6.

Procedure

Three values of the FI schedule were used: 20, 80, and 320 sec and five reinforcer durations: 2, 4, 8, 16 and 32 sec. Subjects were first trained on one of the three FI values until responding was stable; during training on a given schedule value (baseline) the reinforcer was always 4-sec. access to grain. Three reinforcement magnitude test sessions were then conducted, the five reinforcers being presented randomly at the end of each fixed interval. The schedule value was then altered and the same procedure followed until magnitude test sessions had been conducted on the three FI values. The order of conditions and the number of sessions on each condition are shown in Table 7. The criteria for stability and session length were the same as used in Experiments 5 and 6.

RESULTS AND DISCUSSION

The top panel of Figure 23 presents duration of postreinforcement pause from the three baseline FI schedules (unconnected points) and following different reinforcer durations during test sessions on each FI value (connected points). The interquartile ranges of these durations are given in Table 7. On the FI 20-sec schedule there was little effect of reinforcer duration on the subsequent pause; there was evidence of some increase in pause following reinforcer durations of up

Figure 23. Experiment 7: Postreinforcement pause
data from the last three sessions of the baseline (FI)
schedules (unconnected points) and following different
reinforcer durations during the three test sessions on
each FI value (connected points), as functions of
reinforcer duration. Mean postreinforcement pause
duration is shown in the top panels, relative post-
reinforcement pause in the bottom panels.
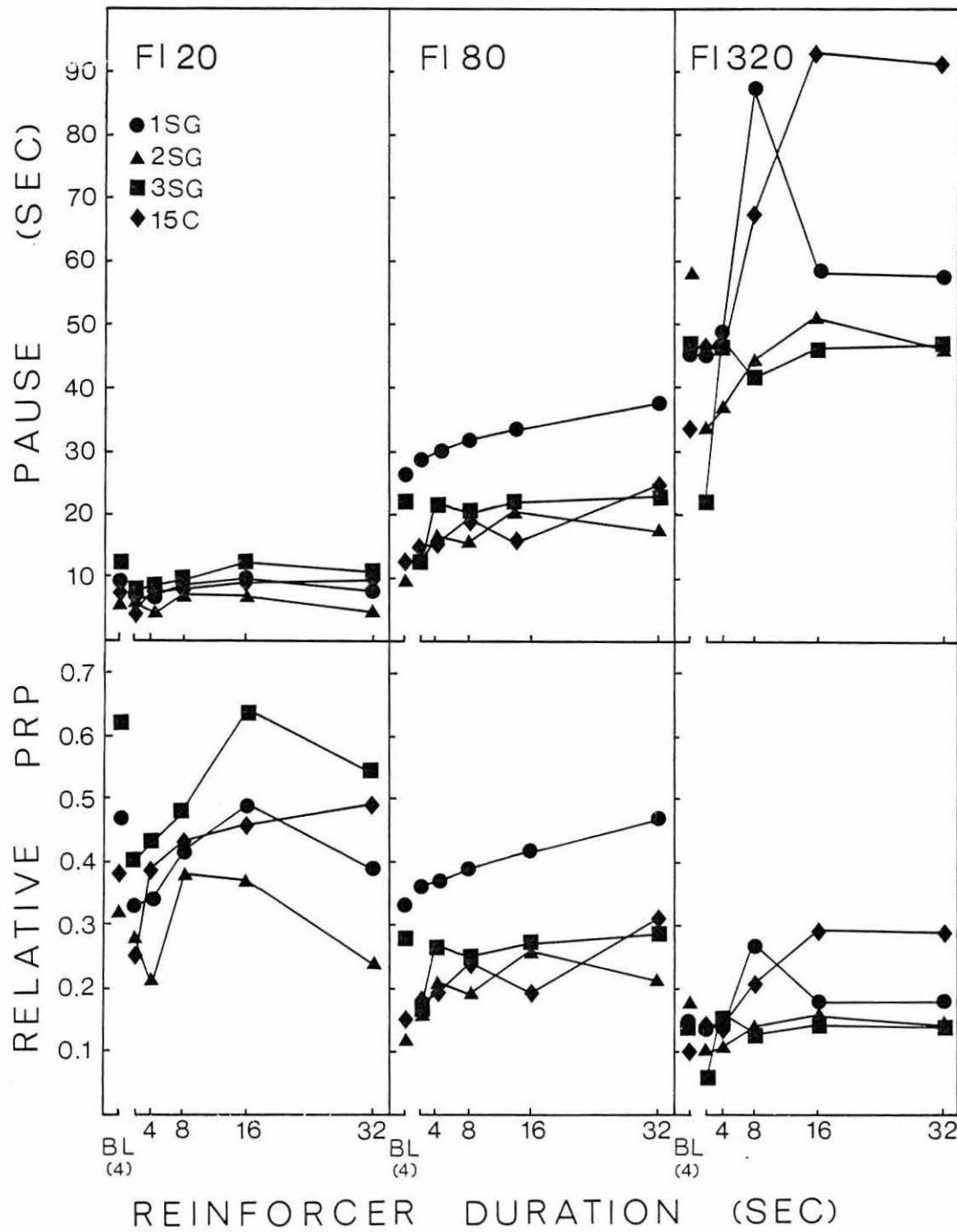
to 16 sec. and in some subjects pause declined again on the 32-sec
reinforcer. Pause durations were longer on FI 80 sec. and increased
as a negatively accelerating function of prior reinforcer duration,
the curve for one subject, 2SG, showing a downturn following the
longest reinforcer duration. The greatest effects of reinforcer
duration were seen on the FI 320-sec schedule, where differences in
pause of up to 45 sec. were produced by differences in reinforcer
duration; for most subjects pause increased with increasing rein-
forcer duration though there was again evidence of a downturn on the
32-sec reinforcer.

While these data might suggest a discontinuity of function
between the FI 20-sec schedule, where there appeared to be little
effect of reinforcer duration, and the longer FI values of 80 and
320 sec (cf. Starr and Staddon, 1974), the relative postreinforcement
pause data indicate otherwise. The lower panel of Figure 23 shows
that when pause is considered in relation to the prevailing schedule
parameter, the effects of reinforcer duration on FI 20-sec pausing
appear to be as least as great as on either FI 80 or FI 320 sec. This
point is supported by the results presented in Figure 24 which show
group postreinforcement pause data on each schedule value; the broken
lines connect pause on the shortest reinforcer to that on the longest
thus indicating the degree of change in pause over the five
durations of the reinforcer. The left panel shows that on the FI
320-sec schedule the change in pause duration, as indicated by the
steep slope of the broken line, was considerable; on FI 80 sec the
slope of the line is much less steep and on FI 20 is almost horizontal.

Figure 24. Experiment 7: Group mean postreinforcement
pauses (left panel) and group mean relative postrein-
forcement pauses (right panel) from the last three
sessions of the baseline FI schedules (unconnected
points) and following different reinforcer durations
during the three test sessions on each FI value
(connected points), as functions of
reinforcer duration.
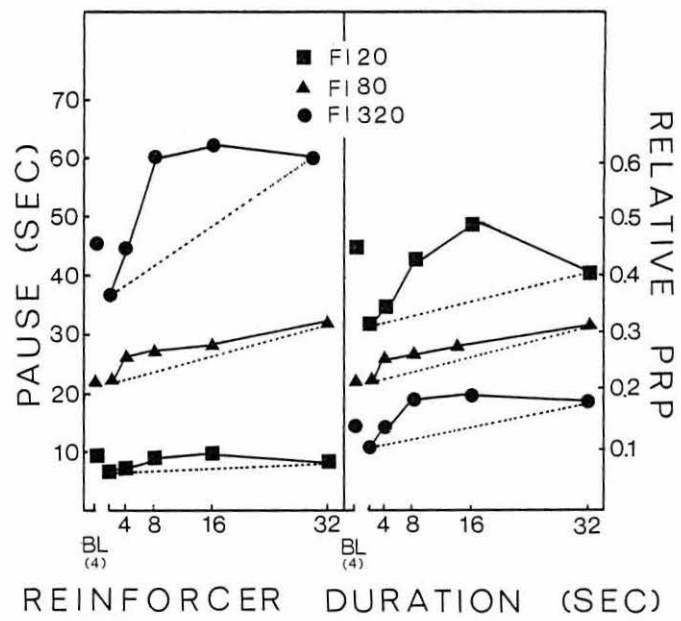
On the other hand, the connecting lines for the relative pause functions, (right panel) have the same slope for all three FI values, showing that relative pause was equally affected by reinforcer duration on all three schedules.

The results presented in Figure 23 and 24 also replicate the findings of Experiments 4 and 5, in that they show that postreinforcement pause occupied a declining portion of the fixed interval as the schedule parameter was increased. This was true of pauses in the baseline and in test sessions. Thus the left panel of Figure 8 shows that FI 120-sec pauses were the longest and FI 20-sec pauses were shortest. The order is reversed however for the relative pause functions which show longest relative pauses on the FI 20-sec schedule.

These results also extend the findings of Experiment 5 in that they show that even in contrasted reinforcement conditions relative pause declines as a function of FI value when reinforcer duration is a constant proportion of the FI value. Thus Figure 24 shows that the relative pause after the 2-sec reinforcer on FI 20 is greater than that following the 8-sec pause on FI 80 which is in turn greater than that following the 32-sec reinforcer on FI 320.

Response rate data are presented in Figure 25. In agreement with the findings of Experiments 4 and 5, this shows that running rate was a declining function of schedule parameter. The effect of reinforcer duration appeared also to be related to schedule value. With increasing reinforcer duration there was little systematic change in running rate on the FI 20-sec schedule; some evidence of a decline

Figure 25. Experiment 7: Mean running rates and
overall rates from the last three sessions of the
baseline FI schedules (unconnected points) and following
different reinforcer durations during the three test
sessions on each FI value (connected points) as functions
of reinforcer duration.
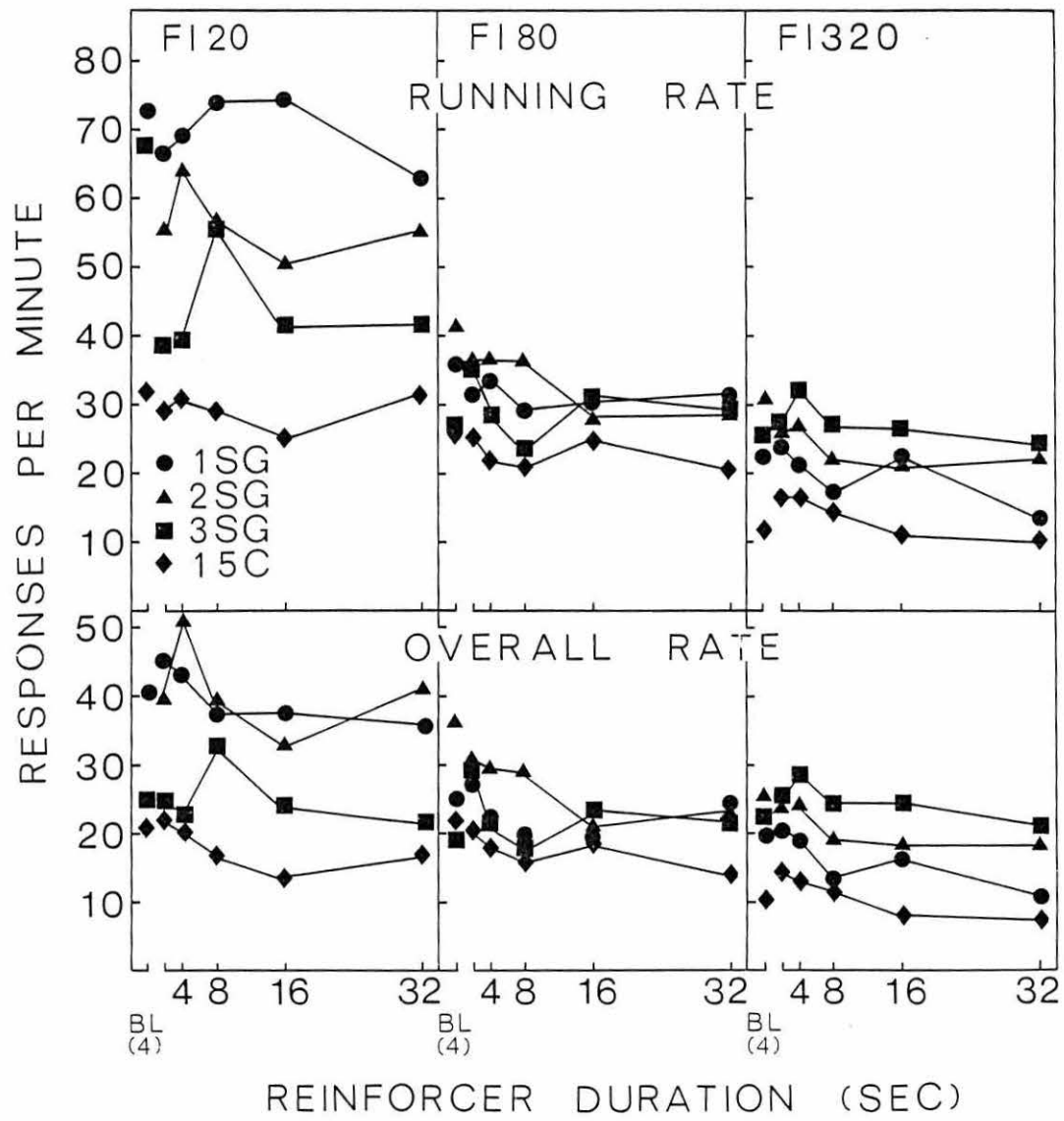
in the case of all four subjects on FI 320. The overall rate
functions generally mirrored the running rate results.

GENERAL DISCUSSION

The present experiments showed that for both rats and pigeons
the duration of postreinforcement pause was not a constant but a
declining proportion of fixed-interval value. This was found to be
the case even when as in Experiments 5 and 7 the duration of the
reinforcer was a constant proportion of schedule value. These results
are also supported by studies of FI performance in other species.
For example Kelley and Powell (1977) using crows as subjects found
that pause increased as a negatively accelerating function of FI value.
Recent studies of human FI performance (cf. Lowe, Harzem and Bagshaw,
1978; Lowe, Harzem and Hughes, 1978) have also reported a negatively
accelerated increase in postreinforcement pause when related to FI
parameter. The evidence from these experiments clearly indicates,
that, for a large number of different species, postreinforcement
pausing on FI schedules cannot be adequately described by a linear
equation: duration of postreinforcement pause does not bear a constant
proportional relation to FI value. This, of course, raises the
question of what is the best quantitative description of the pause/
interval relationship.

A considerable amount of parametric research has recently been
conducted to determine the relationship between the temporal parameters
of schedules and behaviour. For example, in an early study Catania (1970)

showed that the relationship between IRT requirement and emitted IRT duration was well described by a power function of the form:

$$Y = kx^n$$

where Y is the duration of the emitted IRT, X is the IRT criterion and k and n are empirically derived constants. Analysing the data from a number of temporal differentiation studies, Catania found power functions with a slope (n) of less than one "such that the temporal spacing of responses overestimates the schedule value at short durations and underestimates it at long durations (p.28"

Experiments followed which appeared to confirm Catania's analysis. For example, Ferraro and Grilly (1970), Platt, Kuch and Bitgood (1973) and Kuch (1974) found that when specific lever-press durations were reinforced in rats, the relation between obtained response duration and that required for reinforcement was a power function, with an exponent of less than one. In a series of experiments, De Casper and Zeiler (1974, 1977) imposed time limits upon fixed-ratio behaviour and found that power functions with fractional slopes described the relationship of different behavioural measures with the temporal parameter. Most of the investigators mentioned have stressed the similarity between these power functions and the psychophysical law (Stevens 1957) and have suggested that similar processes underlie human performance in psychophysics experiments and animal performance on differentiation schedules. Gibbon (1977) and Platt (1978) have, however, questioned the validity of the power law interpretation, Gibbon reanalysed the data of Platt, Kuch and Bitgood (1973) and found that when response duration was related, not to the duration require-

ment, but to the obtained distribution of reinforced response
durations, proportionality was obtained. A similar reanalysis of
Catania's (1970) data was less successful in yielding proportionality
but produced functions with slopes closer to one (proportionality)
than Catania's analysis. Gibbon's treatment of these data highlights
difficulties in the use of some temporal differentiation schedules
as psychophysical scaling procedures. Platt (1978) points to two
important respects in which such schedules differ from the human
scaling procedures reviewed by Catania (1970): (i) because the rein-
forced times which actually occur on a schedule will often differ from
the minimum requirement specified by the schedule, it is not clear what
is the temporal relationship which controls behaviour e.g. the
specified minimum IRT or reinforced IRT distribution. (ii) unlike the
human situation where feedback is purposely withheld, "correct"
responses on temporal differentiation schedules will result in rein-
forcement and "incorrect" responses will not.

These difficulties do not apply for performance on the FI schedule.
Given stable performance on FI, there is an almost perfect synchrony
between scheduled and obtained interreinforcement times. Moreover, if
postreinforcement pause is taken as the dependent variable response-
produced feedback is also attenuated; responses terminating the
postreinforcement pause are almost invariably followed by non-reinforce-
ment and do not alter the frequency of reinforcement. With these
considerations in mind, power functions were fitted to the postreinforce-
ment pause data of Experiments 4 and 5 of the present study. Figure 26
shows for individual rats and pigeons mean pause duration plotted as a

Figure 26. Experiments 4 and 5; Mean postreinforcement
pause durations (y), plotted as a function of fixed-
interval value (x) on logarithmic co-ordinates. The
data are for rats (left panels), pigeons in the constant
(c) reinforcer conditions (centre panels), and pigeons
in the variable (v) reinforcer conditions (right panels).
The power functions and coefficient of determination
(r^2) are given for each animal.
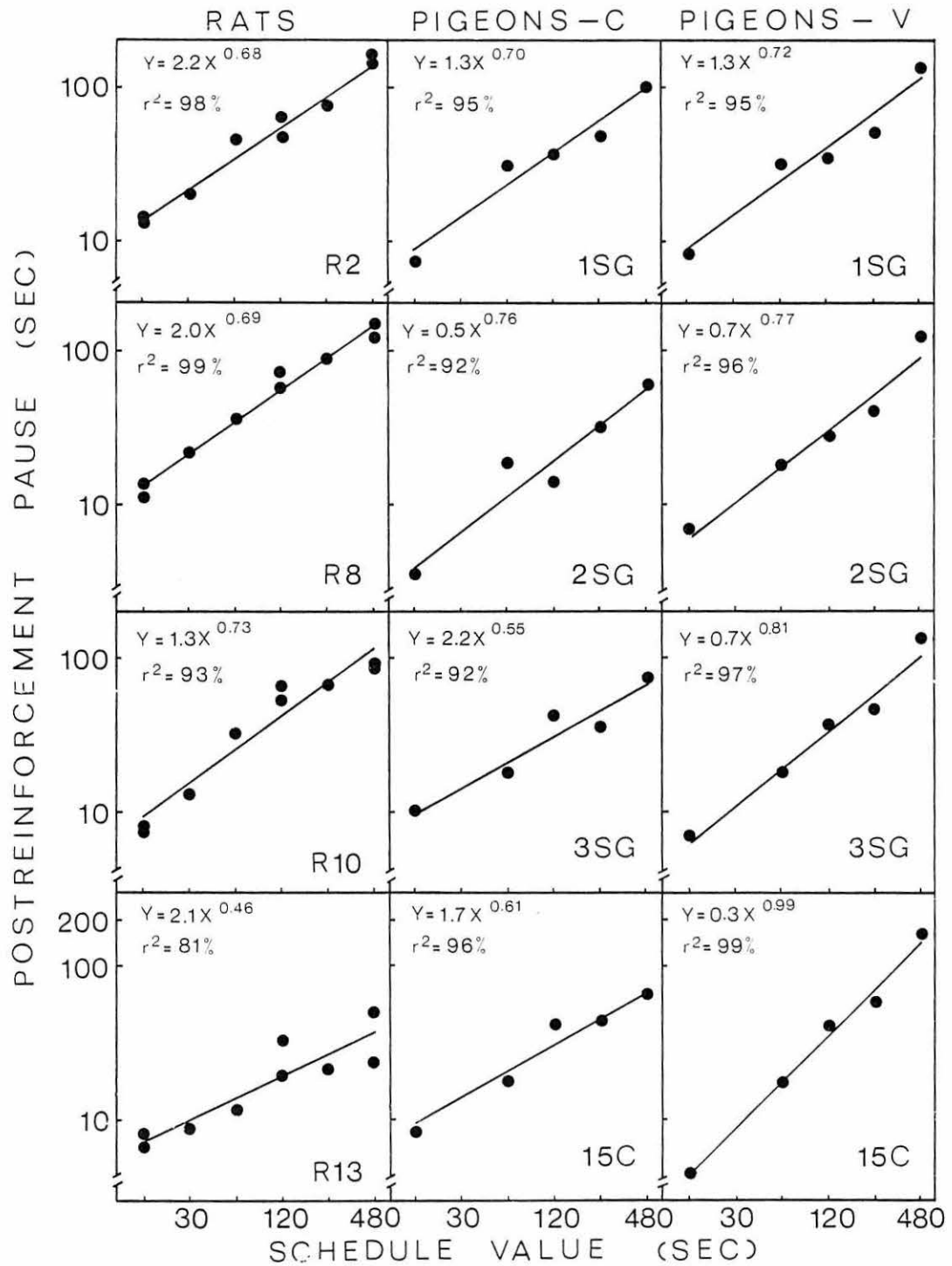
function of FI value on logarithmic co-ordinates. The data from
the rats were well described by a power function, y in this case
representing the duration of the postreinforcement pause and x
the value of the FI schedule. The slopes of the functions were all
less than one, the value of n for three of the subjects falling
between 0.68 and 0.73. The pigeon data from the comparable condition
i.e. constant reinforcement, showed very similar relationships, with
slopes ranging from 0.55 to 0.76 for individual birds. The effect
of the variable reinforcer duration (which increased as a proportion
of schedule value) was to produce a steeper slope than the constant
reinforcer for all animals, although the value of n remained less
than one for each subject.

In order to further investigate the generality of the power
relation on FI schedules the data from Kelley and Powell (1977), who
used crows as subjects on different FI schedules, were replotted on
logarithmic co-ordinates. Figure 27 shows postreinforcement pause
data from Phase 1 and 3. of their experiment (an intervening phase
consisted of performance on FT schedules). Fitted power functions
well described the data and yielded n values very similar to those of
the rats and constant reinforcer pigeons of the present study. To
complete the species comparisons, Lowe (1978) has found that power
functions also describe the performance of human subjects on FI
schedules; in experiments which employed a response-contingent clock
postreinforcement pauses of all subjects were related to FI value by
power functions with slopes of less than one, closely resembling the
animal functions of the present study.

Figure 27. Mean durations of postreinforcement pause
in crows (y), plotted as a function of fixed - interval
value (x) on logarithmic co-ordinates. The power
functions and coefficient of determination (r^2) are
given for each bird (Kelley and Powell 1977).
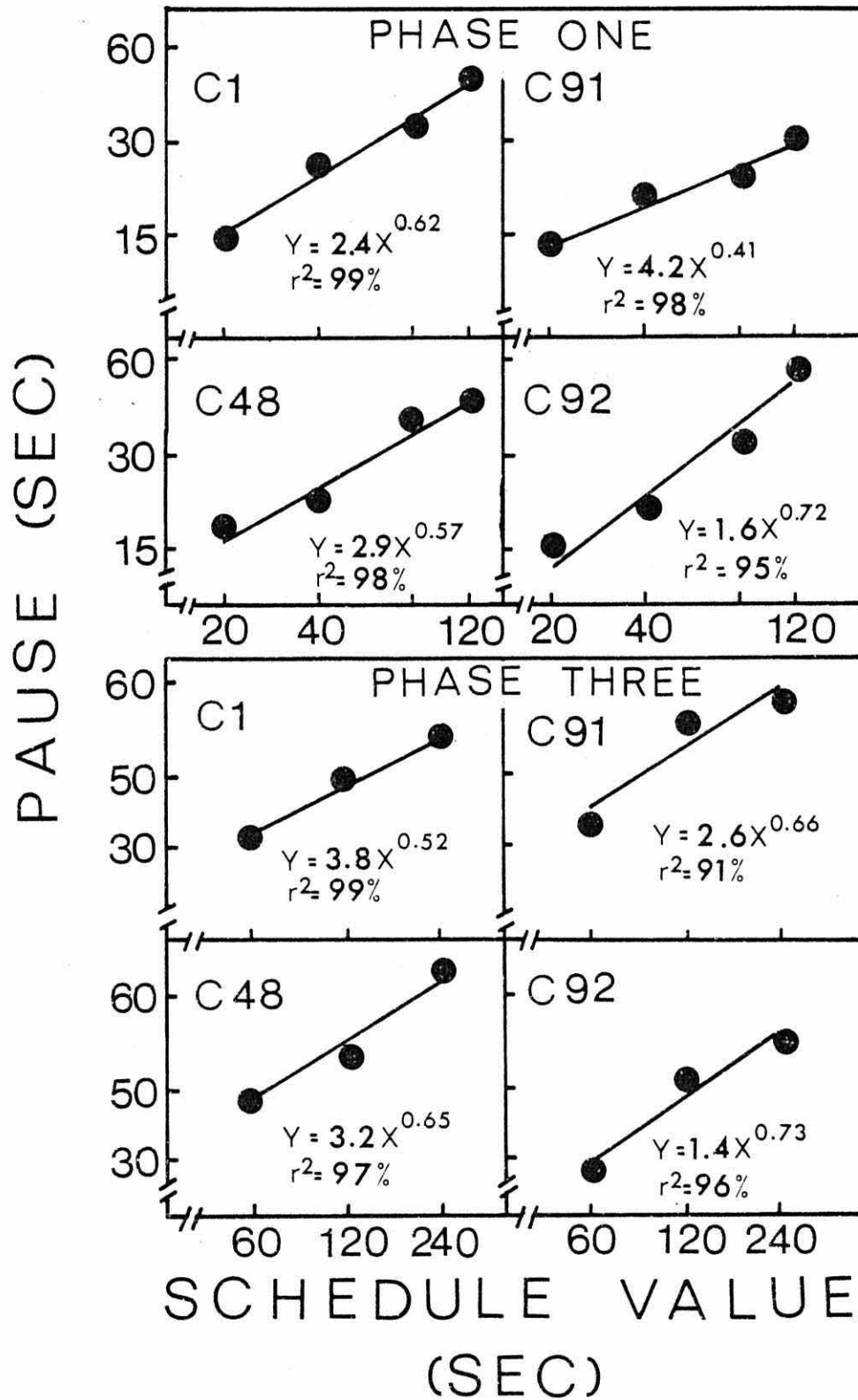
The power relation observed here for postreinforcement pauses on FI schedules also extends to pause relationships with other schedule parameters. For example, analysis of the data presented in chapter six for the simple IRT>t schedules (cf. Harzem, Lowe and Spencer 1978), shows that when IRT requirement was varied between 10 and 120 sec duration of the postreinforcement pause was related to the IRT requirement by power functions; for rat P2 $Y = 2.8 x^{0.662} r^2 = 95\%$; P8 gave $Y = 3.0 x^{0.63} r^2 = 96\%$; P10 gave $Y = 2.7 x^{0.64} r^2 = 93\%$; P13 gave $Y = 2.9 x^{0.52} r^2 = 79\%$; where Y = mean postreinforcement pause and X is the value of the IRT>t value. These data fail to support the natural rate hypothesis of Staddon (1975a), according to which there is a dependence of IRT>t performance on absolute time that is greater than on other temporal schedules such as FI..

Innis and Staddon (1971) studied the relationship between pause and interval duration on cyclic interval schedules, with intervals ranging from 2 to 40 sec; fitted power functions to the group data of five pigeons yielded exponents (n) of 0.824 (mixed schedule) and .894 (multiple schedule) with respective k values of .604 and .434. An interesting feature of Innis and Staddon's interpretation of their data is that because their results deviated from the proportional relationship which, on the basis of the existing FI literature, they expected to find, they assumed that the fractional slope was due to some special limitation on temporal control in cyclic schedules.

The evidence clearly indicates a direct power relation between performance and the temporal requirements of reinforcement schedules.

The data from FI studies in particular show that the relationship is not, as Gibbon (1977) and Platt (1978) have suggested, merely a byproduct of the difference between the mean reinforced interval and the minimum interval required for reinforcement. While such a difference is observed on some temporal differentiation schedules it is almost entirely absent on FI and hence cannot be said to produce the power relation. The appeal to the notion of control by the mean reinforced duration rather than by the minimum duration required for reinforcement is, moreover, beset by other difficulties not least of which is (i) the confounding of dependent and independent variables thus entailed and (ii) the assumption that "on the average subjects time the mean of the reinforcement distribution not its lower limit" (Gibbon, 1977, p.293); a number of studies of schedule performance have shown that when more than one time requirement is in operation responding is governed not by the simple average of the reinforced intervals but is more closely related to their lower bound, as was observed in chapter six (cf. Harzem Lowe and Spencer 1978; Logan 1967). The present account thus suggests that power relations obtained in other temporal differentiation studies (e.g., Catania, 1970; Harzem Lowe and Spencer 1978; Platt Kuch and Bitgood 1973) reflect a real causal, rather than artifactual, relationship between the duration of the temporal requirement and behaviour.

Fractional exponent power functions have now been recorded in a variety of situations where temporal control of behaviour may be said to exist, namely: (i) the performance of animals on FI and other temporal differentiation schedules, (ii) animal psychophysical

experiments on duration discrimination (cf. Stubbs, 1978), (iii) the performance of human subjects on FI schedules (cf. Lowe, 1978) and (iv) human time estimation experiments (cf. Catania, 1970; Eisler, 1975; 1976). The close resemblance between these functions supports the suggestion that similar temporal processes are operative in each case (Catania, 1970; De Casper and Zeiler, 1977; Stubbs, 1978). Certainly, the evidence confirms and extends the observation made by Catania (1970 in relation to IRT>t schedules and human temporal judgments: "the essence of the functional relationship is that the correspondence of temporal properties of response to temporal properties of the environment is not linear" (p.34).

While previous papers have often stressed species differences in the temporal control of behaviour (Lowe and Harzem, 1977; Lowe, Harzem and Bagshaw 1978; Lowe, Harzem and Hughes 1978) a feature of the present postreinforcement pause data is the remarkable similarity of functional relationships both within and between species. These results confirm the findings of previous studies showing that post-reinforcement pause is a sensitive dependent variable which shows orderly and systematic relationships with a number of independent variables (cf. Harzem Lowe and Spencer 1978; Shull, 1978) and suggest that pause relationships may be relatively free of interference from food-induced behaviours (Lowe and Harzem, 1977) or, in the case of humans, interference by verbal formulations of the contingencies (cf. Lowe, 1978).

The present results pose serious difficulties for Gibbon's (1977) Scalar Expectancy Theory, which specifies a proportional rather than

power, relation between postreinforcement pause and interval value.
Experiments 4, 5 and 7 clearly showed that such proportionality
does not hold for animal performance on FI schedules. An additional
difficulty for the theory lies in the magnitude of reinforcement
effects of Experiments 5 and 6. According to Gibbon, changes in the
magnitude or duration of the reinforcer should not, apart from
contextual effects, alter temporal discrimination, i.e. duration of
postreinforcement pause. However, Experiments 5 and 6 showed that
the effects of reinforcer duration on pause were not solely contextual,
though the effects were enhanced when different reinforcers were
presented in the same session. The pause data from the constant and
variable reinforcer conditions of Experiment 5 (Figure 26), showing
that the slope of the power functions was consistently higher in the
variable condition, demonstrates the importance of reinforcer duration
in the determination of the pause/interval relationship.

These results are in agreement with other studies which have
investigated the role of stimulus factors in human and animal psycho-
physical experiments (cf. Ornstein, 1969; Stubbs, 1978). For example,
Stubbs, Vautin, Reid and Delehanty (1978) signalled intervals by either
food, a brief stimulus or a 2.5 sec stimulus. When pigeons had to
discriminate the duration of these intervals accuracy of performance
was found to be good when either food or the 2.5 sec stimulus
initiated the interval but was poor when the less salient 0.5 stimulus
began the interval. While the present experiments confirm that the
stimulus marker, i.e., the reinforcer in this case, is an important
determinant of temporal control, they also show that the effects of

different stimulus markers depend upon the context of presentation, e.g., whether presented singly or contrasted, and point to a complex interaction between the nature of the stimulus and the duration of the interval it initiates.

CHAPTER EIGHT

CONCLUSION

The major findings of this thesis are concerned with the effects of
(i) the temporal parameter and (ii) the nature of the time marker (the
reinforcer) on the postreinforcement pause on temporally-defined
schedules of reinforcement.

The results show that on FI and IRT>t schedules the reinforcing
stimulus comes to exert discriminative control
over responding, producing a postreinforcement pause (cf. experiments
1, 5, 6 and 7; Staddon 1972a). Previous reports have suggested that
increases in response latency following increases in reinforcement
magnitude only occur when such magnitudes are contrasted closely in
time, both in free-operant studies (Hatten and Shull 1972; Harzem, Lowe
and Davey 1975a) and in the double-runway (Amsel 1962; Amsel and Roussel

1952). However, as experiments 5 and 6 showed, whilst the context in
which reinforcement magnitudes are presented is an important determinant
of the postreinforcement pause, the effect can be observed between single
magnitude conditions, providing the differences in reinforcement
magnitude are great enough.

One explanation of the single reinforcement magnitude effects
observed in experiments 5 and 6 is that the presentation of a large
magnitude of reinforcement may demotivate the organism momentarily.
Such an explanation has in fact been postulated to occur in runway
situations (cf. Seward, Perebroom, Butler and Jones 1957). However,
none of the consummatory mechanisms suggested by Seward and his co-
workers can account for the fact that the reinforcement magnitude effect
is greater on an FI 320-sec schedule than on an FI 20-sec. schedule
(experiment 7). The only explanation that appears to be able to account
for the effects observed in this thesis and the experiments reviewed
earlier is that where the reinforcer predicts a period of non-reinforce-
ment, the reinforcer develops inhibitory temporal control over responding.

In experiments 2 and 3 the post reinforcement pause did not bear a simple
relationship to mean interreinforcement interval. In experiment 2 the same
mean interreinforcement interval produced different postreinforcement
pauses and experiment 3 showed that mean interreinforcement interval
could be increased greatly without affecting the post reinforcement
pause (cf. Logan 1967). It was the particular schedule parameter that
appeared to exert control over responding rather than mean interrein-
forcement interval; where animals were given two schedule alternatives

the duration of the postreinforcement pause was the same as that which occurred on the schedule which produced the shortest pause of the two.

The results of the experiments reported have relevance for two current theories of temporal control, i.e. the natural rate hypothesis (Staddon 1972a) and scalar expectancy theory (Gibbon 1977).

Firstly, the natural rate hypothesis (Staddon 1972a, 1975a) was found to be inconsistent with the finding (i) that number of inter-reinforcement responses did not affect the postreinforcement pause on IRT>t schedules (experiments 2 and 3) and (ii) that the relationship between schedule value and postreinforcement pause on FI schedules was the same as that observed on IRT>t schedules (experiments 4 and 5). The natural rate hypothesis predicts that there should be a greater effect of absolute time on IRT>t schedules than on FI schedules.

Secondly, scalar expectancy theory (Gibbon 1977) is inconsistent with present findings. It was found that animals time to the lower limit of the reinforced durations rather than the mean (cf. experiments 2 and 3; Logan 1967) and that the post reinforcement pause-schedule value relationship on FI schedules is best described by a power function with an exponent of less than one. Experiments involving rats, pigeons, crows and people all produced this relationship. In contrast, scalar expectancy theory predicts that animals time to the mean of reinforced durations, and that the pause-schedule value relationship on FI schedules is linear (Gibbon 1977).

One explanation of the power law on temporal schedules is that the postreinforcement pause represents a psychophysical judgment of temporal properties of the environment (see Stevens 1957). The possible advantage of this approach is that it brings together experiments in human psychophysics, human operant behaviour, animal psychophysical experiments and animal operant behaviour.

Further experiments are necessary to follow this point up. For example, whilst evidence suggesting that the power relation results from psychophysical judgments of time is strong (cf. Catania 1970; Eisler 1975; 1976; Stubbs 1978), power functions have been found to describe relationships in biological science which apparently are not dependent on such judgments (Schmidt-Neilsen 1972; Staddon 1978).

The psychophysical approach would certainly encompass the major finding of the present thesis; the postreinforcement pause on temporally-defined schedules of reinforcement results from the occurrence of an event, in this case reinforcement, which signals a period of time of low reinforcement probability. The same type of interaction is also found in both human and animal psychophysics experiments (cf. Stubbs 1978).

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