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Whitaker, John Simon

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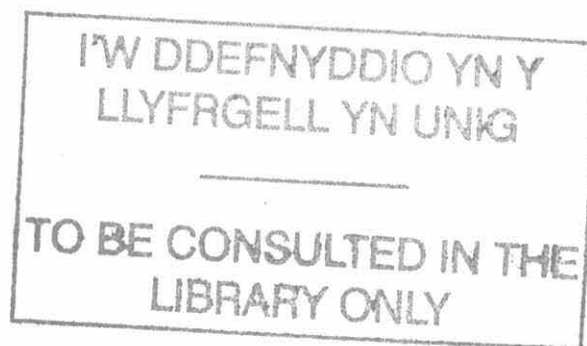[Link to publication](#)

TEMPORAL CONTROL OF

ANIMAL OPERANT PERFORMANCE

A THESIS SUBMITTED

BY

JOHN SIMON WHITAKER.

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A B S T R A C T

This thesis is concerned with the behaviour of
animals on a simple irregular temporally defined schedule
of reinforcement, the two-valued mixed fixed interval.
Experiments I and II showed that the major determinant of
the postreinforcement pause on an evenly probable two-
valued mixed fixed interval was the duration of the short
interval.   It was also found that, if the difference between
the two was great enough, the distribution of local rate of
responding around the end of the short interval took on an
inverted U shape.

Experiments III, IV and V went on to investigate
this pattern of responding in more detail.   The results of
these experiments showed that the local rate of responding
up to the end of the short interval in an evenly probable
mixed fixed interval was very similar to the local rate of
responding on an ordinary fixed interval.   The inverted
U-shaped distribution of local rate of responding developed
when there was a sufficient difference between the two
intervals making up the fixed interval, the position of the
peak of the distribution and the variation of the distribution
being determined solely by the duration of the short interval.
It was argued that this distribution of local rate of
responding constituted a gradient of temporal generalization.

Experiments VI, VII and VIII investigated the
effect upon behaviour of varying the probability of
reinforcement at the end of the short interval.   It was
found that when the probability of reinforcement at the
end of the short interval was 0.5 or above, the pattern of
responding was unchanged.   When the probability fell below
0.5, however, it was found that there was a systematic
increase in the postreinforcement pause, as well as a
decrease in the local rate of responding around the end of
the short interval.

CONTENTS.

CHAPTER 1

INTRODUCTION.

Skinner (1953) has emphasized the importance of the temporal relationship between environmental events in the world outside the laboratory. He states the following :

> 'It is characteristic of the normal environment
> that events occur together in certain temporal
> relations. A stimulus may precede another
> stimulus by a given interval as when lightning
> precedes thunder. A response may produce a
> consequence only after a given interval, as
> when the ingestion of alcohol is followed by
> typical effects after a certain delay. A
> response may achieve its consequence when
> executed at a given time after the appearance
> of a discriminative stimulus, as when a ball

can be hit only by swinging at it after
it has come within reach and before it goes
out of reach. (P.125)'

Within the laboratory situation the study of animal
behaviour goes back to the turn of the century with the work of
Pavlov and Thorndike.   Thorndike (1889) carried out experiments
on the escape of cats from puzzle boxes.   He placed the
cats in a box from which they could escape by operating a latch.
It was found that the behaviour of all subjects followed a
similar pattern.   At first the animal moved wildly about the
box ; at length, by accident, the mechanism was manipulated
and the box opened.   As the experiment was repeated with each
subject it was noticed that after a number of trials the frantic
and useless attempts to claw and push out of the box were
eliminated and the correct movement of operating the mechanism
appeared earlier and earlier in the behaviour of the cat.   These
results led Thorndike (1911) to formulate the Law of Effect, which
stated :

> '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)'

It has since been argued by several authors (cf Catania
1979; Reynolds 1968) that intermittent reinforcement, rather than
one to one response contingent reinforcement, is what generally
occurs in the natural environment. For example, Catania (1979)
states the following :

> 'Relatively few classes of responses have
> consistent consequences. The reinforcement
> of some responses, but not others, sometimes
> called intermittent or partial reinforcement,
> is a general feature of behaviour. For
> example, winning is not an invariable
> consequence of placing a bet, and finding a
> particular commodity is not an invariable
> consequence of going to a store, and getting
> an answer is not an invariable consequence of
> asking a question......Continuous or regular
> reinforcement, the reinforcement of every
> response within an operant class, is the exception
> rather than the rule. (P.167)'

It is because of this that many investigators have
concerned themselves with the systematic study of schedules of
reinforcement (cf Skinner 1938; Ferster and Skinner 1957; Morse
1966 and Zeiler 1977).

Morse (1966) defines a schedule of reinforcement as follows :

> 'A schedule of reinforcement is a prescription
> for initiating and terminating stimuli,
> either discriminative or reinforcing in time
> and in relation to some behaviour. (P.60)'

From this definition it follows that all schedules describe a relationship between different environmental events within a temporal context.   The degree to which different schedules explicitly express a temporal relationship between events differs from one schedule of reinforcement to another. Some schedules such as fixed-interval (FI) and differential-reinforcement-of-low rate (DRL), describe a precise temporal relationship.   On an FI schedule the first response that occurs after a fixed amount of time since the last reinforcement has elapsed is reinforced ; in the case of DRL, the first response is reinforced, after a fixed amount of time has past since the last response.   On other schedules such as fixed-ratio (FR), where the animal must make a fixed number of responses before reinforcement is delivered the temporal relationship between events is more implicit ; since it will take the animal a minimum amount of time to emit the responses, there will be a minimum amount of time between successive reinforcement

deliveries (cf Killeen 1969). Even on a continuous reinforcement schedule (CRF) on which the animal is reinforced for every response which it makes, there is still a temporal relationship between the events specified, the response having to be made before reinforcement is delivered.

It would follow that an understanding of an organism's behaviour under simple temporal contingencies such as those provided by schedules of reinforcement would go some way to our understanding of behaviour in general. It would appear from the above that, not only do temporal relationships underlie the behaviour in the laboratory study of schedules of reinforcement, but also in most of the behaviour in the natural world.

The concern of the present thesis is to investigate the determinants of behaviour on irregularly temporally defined schedules of reinforcement. It will be attempted to determine the degree to which temporal discrimination, which it has been argued plays a large part in determining behaviour on the regular temporally defined schedules (cf Staddon 1972a; 1974), also determines behaviour on the irregularly defined schedules.

Dependent Variables.

Early research on schedules of reinforcement used, as its major dependent variable, 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.'

One fundamental difficulty in using overall rate of responding as the sole dependent variable is that it is found not to be constant across interreinforcement intervals on several schedules of reinforcement (cf Dukich and Lee 1973; Catania and Reynolds 1968; Ferster and Skinner 1957). Since this is the case, it can be argued that the overall rate of responding across a session on a particular schedule is determined by the local fluctuations in the rate of responding across the interreinforcement interval. So to understand the determination of the overall rate of responding, the controlling variables of the local rates of responding across the individual interreinforcement intervals must first be understood (cf Catania and Reynolds 1968).

It is found on the schedules of reinforcement that
produce an approximately constant interreinforcement interval,
i.e. fixed-interval and fixed-ratio (Killeen 1969), that the pattern
of behaviour produced by many animal species is very similar.
On both schedules there is a pause in responding after reinforce-
ment, for about a third to two thirds of the interreinforcement
interval (cf Ferster and Skinner 1957), followed by responding
until the next reinforcement. It has been further demonstrated
(Felton and Lyon 1966; Lowe, Harzem and Spencer 1979; Powell 1968)
that this postreinforcement pause is functionally related to the
schedule parameters (cf Neuringer and Schneider 1968) and would
give a good measure of the degree to which changes in different
temporal aspects of a schedule affect behaviour.

On the more irregularly temporally defined schedules of
reinforcement, such as variable interval (VI) (i.e. where the
first response after a variable amount of time since the last
reinforcement is reinforced), the relationship between the
postreinforcement pause and the schedule parameters is less well
understood. Performance on these irregular schedules is
generally described in terms of gross variables such as the
overall rate of responding and the average interreinforcement
interval (cf Skinner 1950; Herrnstein 1961; 1970). It is
apparent, however, from the cumulative records presented by
Ferster and Skinner (1957) and others and the studies that have

taken detailed measures of postreinforcement pause (cf Martin 1971), that there are local variations in the rate of responding across interreinforcement intervals on these schedules. The manner in which the distribution of intervals making up the schedules determines the fluctuations in the rate of responding within an interreinforcement interval have only been considered quantitively in comparatively few studies.

The postreinforcement pause alone is also an inadequate measure to reflect the variation of temporal properties of the schedule upon behaviour, since on irregular schedules the pause only accounts for a small fraction of the average interreinforce- ment interval (Ferster and Skinner 1957; Farmer 1963; Lachter 1971; Harzem, Lowe and Priddle-Higson 1978). It is, therefore, necessary to use another measure that reflects variations in the rate of responding across the interreinforcement interval. Catania and Reynolds (1968), in a study that will be described in detail in the next chapter, used a measure they termed the local rate of responding. The interreinforcement intervals were divided into several smaller intervals or bins, the average rate of responding being calculated separately in each bin. They found that this measure showed that there were fluctuations in the rate of responding at particular times after reinforcement, corresponding to the fluctuation in the probability of

reinforcement at those times. This measure would thus seem to reflect fluctuations in behaviour across an interreinforcement interval. It is, therefore, proposed to use this measure together with the postreinforcement pause, as the major dependent variable.

Thesis Plan.

The next chapter is a selective review of the existing literature on the effects of temporal control upon the behaviour of animals on schedules of reinforcement. It will attempt to show the relationship between the probability of an animal receiving reinforcement at a particular time and the probability of the animal making a response. Chapter 3 is a selective review of the recent literature on the psychophysical aspects of animal timing, giving particular emphasis to an animal's temporal sensitivity and to the relationship between the actual duration of a stimulus and the animal's judgment of it. A series of experiments is reported which investigate the performance of animals on simple irregular temporally defined schedules of reinforcement. The results are discussed with reference to temporal discrimination and generalisation in the determination of schedule performance.

CHAPTER 2

TEMPORAL CONTROL AND PERFORMANCE
ON SCHEDULES OF REINFORCEMENT.

Introduction.

There are four basic schedules of reinforcement, two of
which are defined in terms of time, namely fixed interval and
variable interval, and two of which are defined in terms of number
of responses, namely fixed ratio and variable ratio, (cf Blackman
1974). This present chapter is a selective review of the
literature of the performance of animals on these schedules of
reinforcement. It will attempt to isolate the controlling variables,
either explicit or implicit on these schedules. The other major
temporally defined schedule, differential reinforcement of low
rate (DRL), is not dealt with in this chapter but is discussed with
reference to temporal psychophysics in Chapter 3. (For extensive

review of the literature on DRL performance see Harzem 1969 and Kramer and Rilling 1970)

Fixed Interval

The fixed-interval schedule (FI) was first described by Skinner (1938) when it was referred to as periodic reconditioning. There are two different versions of this schedule. In the first one, the reinforcement becomes available after a fixed amount of time has past since the last reinforcement was delivered, and will be delivered for the first response made after this time has past. In the second version the timing is 'by the clock', reinforcement being made available after a fixed amount of time has past since the last reinforcement was made available and delivered for the first response made after this fixed amount of time has past. Hence, when the schedule is timed by the clock a reinforcer will become available in a shorter time than the specified FI value if the previous reinforcer was delivered much later than the time at which it became available.

The typical stable performance on an FI schedule consists of a pause in responding, after reinforcement, which lasts for about half the interval, this is then followed by a gradual acceleration in the rate of responding until a terminal rate is reached (Skinner 1938; Ferster and Skinner 1957). The cumulative form of this performance results in the so called scallop response pattern. Cumming and Schoenfeld (1958) studied the acquisition

of the stable performance on the FI schedule, using pigeons on an FI 30-min. The performance in the early sessions was characterised by responding just after reinforcement and then a low rate of responding before the next reinforcer. The second stage of acquisition consisted of a steady rate throughout the interval, this phase then gradually giving way to the characteristic scallop pattern of responding.

A number of studies (Skinner 1938; Ferster and Skinner 1957; Sherman 1959; Schneider 1969) have reported an alternative pattern of responding on fixed-interval, that of 'break-and-run'. This again has a pause after reinforcement, but instead of a gradual acceleration to the high rate of response, the pause is followed by a rapid transition to a high constant rate of responding ; the point at which this transition occurs is termed break-point (Schneider 1969). It has been argued (Cumming and Schoenfeld 1958; Schneider 1969; and Sherman 1958), that break-and-run represents the truly stable form of responding on fixed-interval schedules and that the scalloped pattern is merely a transient stage characteristic of early performance. This argument is based on the findings of Skinner (1938) and Ferster and Skinner (1957) who showed that break-and-run only appeared after extended exposure to the particular FI value that the animal is trained on. It has also been suggested (Sherman 1959) that the break-and-run pattern occurs more readily with relatively short fixed-intervals of 9-min or less.

A common method used to produce an average scallop over a session is to divide each interval up into segments or 'bins' (usually ten), and then finding the mean rate of responding in each bin, thus giving measure of the changes in the mean local rate of responding across the interval. This method has been used by Killeen (1975) and Lowe and Harzen (1977) to produce an average scallop which was then found to be described by the left hand side of a normal distribution. Unfortunately, this method will fail to reflect a break-and-run pattern, if this is the dominant form of responding in individual intervals. This is simply because the run will start earlier in some intervals than in others. Thus, as the time after reinforcement increases, the percentage of intervals that have past the break-point will increase, and hence so too will the average rate of responding in consecutive bins.

Schneider (1969) used a method of representing the average performance on fixed-interval which attempted to overcome this problem. He defined the break-point as the point of maximum acceleration of the rate of responding in the interval. After finding this point for each individual interval, he then found the mean rate in the 4-sec after the break-point. This process of taking 4-sec bins was then continued both forwards and backwards ; thus a plot of the rate through the interval will result in a low rate up to the break-point and then rapid transition to a high rate.

Schneider, however, admits that one drawback with this procedure is that the number of intervals represented by a particular time period decreases as distance from the break-point to that time period increases in either direction.

Another method was used by Dews (1978), which was capable of showing a break-and-run response pattern. The intervals were divided up into groups, and after determining in which bin the first response occurred, the mean rate of responding across the remaining bins, excluding the one in which the first response was made, were then calculated for each group of intervals. Hence, if, as is the case with break-and-run, the individual intervals all reach terminal rate of responding very rapidly after the first response, the mean rate will be constant. But if, as is the case with the scalloped pattern of responding, there is a steady increase in rate across individual intervals, the mean rate for any group of intervals will also steadily increase. It was reported by Dews (1978) that the pattern of responding on fixed-interval that he observed in this way was scalloped. Other investigators, Lowe and Harzem (1977), have also reported that even when the cumulative records on FI clearly give the appearance of a break-and-run type response pattern that the first few interresponse times (IRTs) show the rate of responding to be positively accelerated.

A number of different dependent variables have been
used to assess the effect of various experimental manipulations
upon FI performance. Probably the most straight forward measure
that has been used is the overall rate of responding, which is
quite simply the number of responses emitted during a session
divided by the duration of the session. This measure, however,
does not take account of the scallop or break-and-run patterning
that is typically produced on FI. A simple procedure that has
been used to take account of this response patterning is to
consider the interreinforcement interval in two parts ; the
division being made at the first response after reinforcement,
this then divides the interval into the postreinforcement pause
and the run time. The second part of the interval is generally
considered in terms of rate of responding, the 'running rate' being
the number of responses emitted in the run time divided by the
run time.

It has been argued by some investigators, notably
Schneider (1969), that the postreinforcement pause is not a very
good measure owing to the fact that a few responses are sometimes
emitted in the time between the delivery of reinforcement and the
break-point. This has led some authors to use alternative measures
of the performance on FI schedules. Harzem (1969) used the
time to the fourth response. Herrnstein and Morse (1957) used a
measure known as 'quarter life', the time taken to emit the first

quarter of the total responses in an interval. A further and more mathematical measure was produced by Fry Kelleher and Cook (1960); their measure, 'the index of curvature' gave a measure of the extent to which the cumulative record departed from a straight line between successive reinforcements.

The degree to which these measures, excluding the index of curvature, convey the changes in response patterning produced by manipulating the FI value was examined by Dukich and Lee (1973). They found that there was a high intercorrelation between postreinforcement pause, time to the fourth response, and quarter life, $(0.78 < r < 0.99)$. Running rate and postreinforcement pause were not highly correlated. They concluded that :

> 'At least two measures seem to be needed
> to describe fully changes in the pattern
> of FI responding. The present results
> suggest that either postreinforcement
> pause or time to the fourth response in
> conjunction with running rate can be used
> to describe many changes occurring in FI
> response pattern (P289).'

It has been suggested, by several authors (Shull 1970; 1979; Schneider 1969), that the postreinforcement pause and the running rate are separately determined ; that is variables that will affect one of these measures need have no

effect upon the other. For example, Killeen (1969) arranged a
small fixed ratio requirement to be completed at the end of
the fixed interval. This contingency had the effect of changing
the running rate but had virtually no effect on the postreinforcement
pause duration.

One variable that does affect both of these parameters
of FI responding is the FI value. The relation between FI value
and the postreinforcement pause has commonly been found to be
positive (Shull 1971; 1979; Dukich and Lee 1973; Lowe, Harzem
and Spencer 1969). The exact relation between the FI value
and the postreinforcement pause is still a matter of some debate
and will be discussed in more detail in the next chapter.

The relationship between running rate and the FI value
is also somewhat ambiguous. Dukich and Lee (1973) exposed rats
to FI 30-sec, FI 60-sec and FI 120-sec. They found that for two
out of three of the rats the running rate decreased as the FI
value increased, with the third rat, however, the running rate
was highest for FI 60-sec, and approximately equal for the other
two values. Lowe, Harzem and Spencer (1979) exposed both pigeons
and rats to FI values ranging between 15-sec and 480-sec, they
reported that for both sets of subjects, the running rate decreased
as the FI value increased.

The postreinforcement pause has often 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
1972a). According to Ferster and Skinner (1957) the reinforcer acts
as a discriminative stimulus. They define a discriminative
stimulus as, 'a stimulus in the presence of which a response is
reinforced, and in the absence of which it goes unreinforced.'
Though this definition applies only to situations in which the
stimulus has a positive discriminative function (S^D or S+) negative
discriminature control also occurs when in the presence of a stimulus
($S^\triangle$ or S-) responses are never reinforced (Ferster and Skinner 1957).
Thus on a fixed-interval schedule, the reinforcer may be said to
be a negative discriminative stimulus since responses will not be
reinforced just after it has been delivered. It is possible that
because Ferster and Skinner had the phrase "in the presence of which"
in their definition of a discriminative stimulus, that this led
them to hypothesise the presence of residual stimuli for
approximately 30-sec after the occurrence of reinforcement. Thus,
in the presence of residual food stimuli the animal did not respond.
This hypothesis would not seem to be consistent with later experimental
evidence. Staddon (1972a) used a neutral stimulus, the appearance,
for 5-sec, of three vertical lines on the response key, to indicate
the start of an FI. It was found, that although this did not
produce any residual stimuli, there was still a typical pause
following the occurence of the vertical lines. Other evidence that

is incompatible with the residual stimuli hypothesis has been reported by Dews (1965) who ran animals on fixed-intervals having values of up to 24 hours. He found that the postreinforcement pause on the FI values was upto 30-min which is clearly longer than residual food stimuli would be expected to last.

Several other theories have sought to explain the pattern of responding observed on fixed-interval. Dews (1962) and Morse (1966), for example, have proposed that the FI scallop is due to the difference in the delay of reinforcement for responses made late in the interval as compared with those made early in the interval. The responses emitted towards the end of the interval are reinforced almost immediately, and hence response strength at this part of the interval is greater than it is early in the interval, where there is a long delay between a response and reinforcement. Morse (1966) has claimed that this interpretation of FI responding does not require the concept of temporal discrimination to explain the scallop response patterning, similarly, Nunes, Alferink and Crossman (1979) have suggested that response number plays a part in determining the pause. Other authors, however, have claimed that the pattern of responding observed on FI is indicative of temporal discrimination in at least some part of the interval (e.g. Catania and Reynolds, 1968; Shull, 1971a). Theories that allow for this can roughly be divided into two camps ; those that would have it that temporal

discrimination occurs in just one part of the interval, either the postreinforcement pause or the run time and those theories that would account for FI performance in terms of temporal discrimination occuring throughout the whole interval.

One theory that belongs in the first camp is that of Schneider (1969) in which FI performance is considered as a two state phenomenon, the first state being a temporally discriminated extinction period, corresponding roughly to the postreinforcement pause, followed by the second state in which the animal responds until the terminal reinforcement. This theory would only allow for temporal discrimination in the first part of an FI interval.

Another more recent theory that would fall into this group is that of Shull (1979). This theory claims that temporal discrimination only occurs in the run time, the duration of which then determines a momentary probability of ending the pause in the next interval, this momentary probability remaining constant throughout a particular pause. If the animal discriminates a long run time this will produce a relatively low momentary probability of terminating the next pause, if the animal discriminates a short run time this will produce a relatively high momentary probability of terminating the next pause. Consequently, on average, long run times should be followed by short pauses and vice-versa.

In the other camp an alternative explanation of the
pattern of responding on fixed-interval has been put forward by
Staddon (1969; 1972a).   He notes the similarity between fixed
interval and the Pavlovian 'inhibition of delay' (see also
Mackintosh 1974).   Pavlov (1927) found that when the unconditioned
stimulus (UCS) was delayed for 3 minutes following the conditioned
stimulus (CS), the conditioned response (CR) did not occur for
some time after the (CS) was presented.   Pavlov attributed the
absence of responding early in the delay interval to the temporal
inhibitory effect of the (CS).   On this analogy Staddon (1969)
states

> 'A stimulus can inhibit responding
> following its offset (or for a time
> following its onset) after the fashion
> of Pavlovs inhibition of delay.   It
> is becoming clear that in the steady-state,
> reinforcement on fixed-interval schedules
> inhibits responding for some time
> following its onset.   (Pp 483 - 484).'

Staddon (1972a) goes on to develop this idea, drawing a distinction
between two forms of stimulus control, situational control and
temporal control.   On situational control Staddon (1972a) 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
response instance cannot be predicted
from any property of the stimulus
(Pp 212 - 213).'

This form of stimulus control is the type Ferster and Skinner

(1957) discuss (cf Terrance 1966).   On temporal control Staddon

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 how long or
short the time separating them, and
no matter what other contextual
dependencies may exist (P.213).'

Staddon's theory thus proposes that the reinforcer on an FI schedule exerts inhibitory temporal control, and is hence an inhibitory stimulus.* As a result the appearance of a reinforcing stimulus on an FI schedule will inhibit responding for a certain amount of time after its occurrence.

There is a considerable amount of evidence for this theory. As was noted earlier Killeen (1975) fitted the left tail of a normal distribution to the geometric mean rates across various fixed intervals. He used data from Catania and Reynolds (1968); Hawkes and Shimp (1975) and Dukich and Lee (1973). The normal distribution accounted for 99.5% of the data variance. Killeen (1975) then went on to test the extent to which a normal curve would account for Pavlov's (1927) inhibition of delay data. He plotted the amount of saliva in 24, 30 sec bins across the 12-min delay interval. He found that as time from the presentation of the UCS increased, so too did the rate of salivation so that it fitted a normal curve which

* An inhibitory stimulus has been defined by Hearst (1972) as :
  'a multidimensional environmental event that, as a result of conditioning (in this case based on some negative correlation between presentation of the stimulus and the subsequent occurrence of another event or outcome, such as the 'reinforcement'), develops the capacity to decrease performance below the level occurring when that stimulus is absent (Pp 6 - 7).' In the present thesis the term 'inhibitory stimulus' also refers to any stimulus which suppresses responding.

accounted for nearly all of the data variation. It would then seem that there is a quantitative similarity between these two procedures. Whether or not this is merely a formalistic fallacy (cf Skinner 1969) remains as a possibility, but there is, however, a substantial body of evidence to support the theory of inhibitory temporal control.

Another similarity between the Pavlovian inhibition of delay paradigm and the FI schedule, comes from the work on disinhibition. Pavlov found that if a novel stimulus is presented early in the delay period, the CR reappeared ; he described this effect as disinhibition.

It has been found that similar effects also occur with an FI schedule. When a novel stimulus is presented early in the interval, there is a reduction in the duration of the postreinforcement 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 notable that when a novel stimulus is presented later on in the FI interval, the effect is to decrease the rate of responding (Heinrichs 1968). This latter phenomenon is analogous to Pavlovian external inhibition, i.e. the unconditioned effect of a novel stimulus which serves to reduce the occurrence of the CR (cf Pavlov 1927).

An experiment by Wilkie (1974) is probably the best demonstration of disinhibitory effect of a novel stimulus on an FI schedule. Wilkie (1974) trained pigeons on an FI schedule in the presence of three vertical lines on the response key. After the birds had become stable, the tilt of the lines was varied in consecutive thirds of the interval. It was found that in the early part of the interval variation in the line tilt produced a U-shaped function of response rate with line tilt. The low rates of responding occurred when the line was vertical as in training, and the highest rate when the line was tilted at 45° from the vertical. In the last third of the interval the opposite effect was found. There was an inverted U-shaped function with the highest rate occurring in the presence of the training stimulus and the lowest in the presence of a line tilt of 45° from the vertical.

This experiment clearly demonstrates the control the stimuli associated with reinforcement has over the rate of responding. The same stimulus has inhibitory properties at the beginning of the interval, since when the stimulus is altered slightly the rate of responding goes up at this part of the interval ; it also has excitatory properties at the end of the interval, since a slight change in the stimulus at this part of the interval results in a reduction in the rate of responding.

If the same stimulus has different effects at different points in
time then it may be concluded that the factor that changes its
effect from being inhibitory to that of being excitatory must be
temporal.   It can also be deduced from the finding that the
change between the excitatory and the inhibitory
effects of the stimulus takes place rapidly at the point in time
when the reinforcement is delivered, that it is this environmental
event that causes the change.

An illustration of the power of the inhibitory effect
of the delivery of reinforcement on an FI schedule is provided
by Skinner and Morse (1958).   They trained a rat on a fixed
interval schedule in which the response necessary to produce
reinforcement was running in a wheel.   This novel response did
not affect the standard scallop type pattern of responding, with
a pause after reinforcement followed by a gradual acceleration
in the rate of running until reinforcement.   The point of interest
to the present discussion was the time for which the rat stopped
running after the delivery of the reinforcement ;   since it was
observed that considerable running occurred in the same wheel
before and after the experimental session, where it was not
reinforced.

Another illustration of the inhibitory after-effects of
reinforcement have been provided by studies that have presented
non-contingent reinforcement in mid-interval on an FI schedule.
Logan and Ferraro (1970) performed an experiment that did just
this, they found that the non-contingent reinforcer had the effect
of producing a pause in responding comparable to the postreinforce-
ment pause following the usual contingent reinforcement.   They
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 the reward even though it
>occurred at an unaccustomed time and
>independent of response (P.121).'

Further evidence is provided by an unpublished study by
Blewitt and Lowe (personal communication) in which both contingent
and non-contingent probe intervals were introduced into an FI
session.   These intervals were both longer and shorter than the
background FI schedule's value.   It was reported that, as with
Logan and Ferrano (1970), that the pause following the reinforce-
ment was comparable to the pause after the reinforcement delivered
at the end of usual interval.   This effect occurred whether or
not the reinforcer was presented non-contingently during the

postreinforcement pause or during the run time.

It would seem though that animals will, after a time, learn to discriminate between contingent and non-contingent reinforcements. Shull and Guilkey (1976) performed an experiment in which non-contingent reinforcers were regularly delivered during the postreinforcement pause on an FI schedule ; it was found that this did not substantially extend the pause, once the animals had been exposed to this condition for some time.

Inhibitory stimulus control has often been reported to be aversive to organisms (Terrance 1966; 1972). Therefore, it would be expected if reinforcement is indeed acting as an inhibitory stimulus on the FI schedule, that periods shortly after the delivery of reinforcement would have aversive properties. This has in fact been found to be the case, Brown and Flory (1972) found that pigeons would respond on a second key to change the stimulus on the response key, during the postreinforcement pause on an FI schedule. Similarly, it is a common finding that elicited aggression occurs in response to aversive stimulation (Azrin and Holz 1966; Ulrich and Azrin 1962; Ulrich, Delaney, Kucera and Caborocco 1972; Hutchinson 1977). It has also been reported on several studies in which a target has been placed in a Skinner box, (either a live animal, usually of the same species, or a dummy) during an FI schedule, that attacks will occur,

usually during the postreinforcement pause (Richards and Rilling 1972).

Staddon (1972a) proposes that the reinforcer develops inhibitory after-effects because it is the best predictor of non-reinforcement in the schedule, in that its appearance signals that there will be no reinforcement for a time equal to the fixed-interval value. Staddon also claims that the behaviour of an organism at any point during a fixed-interval is a function of its relative proximity to reinforcement. Staddon (1972a) describes it as follows :

> 'Reinforcement acts to select properties of behaviour, including both responses and stimulus components. Selection is determined by the relative proximity to reinforcement of properties that vary in time (P.220).'

This Staddon terms the relative proximity principle.

It would seem to follow that if reinforcement develops its inhibitory properties because it signals a period of non-reinforcement in an FI schedule, that if reinforcement was delivered on a schedule in which it signalled more reinforcement, that it would have the effect of elevating the rate of responding rather than depressing it. Staddon (1970(a); 1972(b)) has shown

this to be the case.   He described a schedule in which there was

a high probability of a response contingent reinforcement for the

first 60-sec after reinforcement, followed by a zero probability

of a response contingent reinforcement ;   virtually opposite

conditions than those which occur on an FI schedule.   This was

Staddon's 'go-no-go' schedule with a Vl 60-sec contingency in

operation for the first minute after reinforcement, followed by

a change in the required response from a key peck to not pecking

for 10 seconds or more (DRO 10-sec contingency).   Staddon

reported that this schedule resulted in a reverse scallop pattern

of responding with a very high rate just after reinforcement,

followed by a very low rate.   It would follow that since the

pattern of behaviour following reinforcement can be reversed by

means of reversing the predictive significance of the reinforcer

of forthcoming events, that it is this predictive significance

of the reinforcement that is the critical factor in controlling

behaviour on fixed-interval schedules, and not any special

properties of situations associated with a consummatory response.

A further requirement of Staddon's relative proximity

principle is that a neutral stimulus, such as a light or a tone,

if it has got the same predictive significance as a reinforcer

on an FI schedule, should also have the same inhibitory after-

effects.   The evidence here is slightly more ambiguous.

It has been reported that when some of the reinforcements (R) are replaced by a brief blackout (N) on an FI schedule, that the animal will learn to pause after N as well as after R (Kello 1972; Staddon and Innis 1969; Staddon 1974), it is also consistently found that the pause after N is shorter than that after R, this has been termed the 'omission effect'.

A procedure in which rather better temporal control by a neutral stimulus was achieved on an FI schedule, was described by Staddon (1972a). It consisted of having a VI 60-sec schedule in operation, every four minutes the stimulus on the response key would change from white (W) to white with three vertical bars superimposed on it (WV) for 5-sec. The appearance of this stimulus (WV) signalled that the next reinforcer would be in 2 minutes, after which the schedule would revert to the background VI 60-sec contingency for a further 2 minutes. The result of this procedure was that the pigeons responded at a steady rate during the VI 60-sec period, but when the stimulus (WV) was presented pecking stopped, producing a post-stimulus pause.

Staddon (1972a) noted that there are several experimental findings that the relative proximity principle has difficulty in explaining. These are as follows : (1) The omission effect is dependent upon the FI value ; at small FI values the pause after (N) and after (R) is more or less the same. This might suggest that the inhibitory after-effect

of (N) is absolute rather than relative.   (2) The effect of

varying the magnitude of reinforcement on an FI schedule; it

is found that longer pauses follow a higher magnitude of

reinforcement. For example Jensen and Fallon (1973) and

Lowe, Davey and Harzem (1974) using rats as subjects, have

shown that when the magnitude of reinforcement is manipulated,

that there is a positive relation between the duration of the

postreinforcement pause and the magnitude of reinforcement.

Staddon (1970b) found similar results using pigeons as subjects

and varying the duration for which grain was made available at

reinforcement. However, these studies had different magni-

tudes of reinforcement contrasted closely in time ; rather

than single magnitudes trained to stability. In a more recent

study Spencer (1979) trained pigeons to stability with different

reinforcer durations and found that the pause was positively

related to the magnitude of reinforcement. (3) Similarly,

when the pause follows blackout presented in lieu of reinforce-

ment, the duration of the post-stimulus pause depends upon the

duration of the blackout, longer pauses follow longer blackouts

(Staddon and Innis 1969).

Staddon (1972a; 1974) has sought to explain these

anomalies by reference to the limitations of memory and

attention. He refers to a study by Cowles and Nissen (1937)

on delayed matching to sample, whose results showed that an

animal will recall a high value stimulus, i.e. food, better
than it will recall a low valued stimulus, i.e. blackout.
He also produces evidence from an experiment of his own
(Staddon 1975), that shows, that if two similar neutral
stimuli have different predictive significance for future
events, i.e. food in two minutes or food immediately, that
they will fail to produce differential control even though
it has been shown in a control condition that the two stimuli
can be discriminated between, and that if they have the same
predictive significance they exert control over responding.
Staddon claims that this failure, 'the confusion effect',
occurs because the animals fail to recall which of the two
stimuli was presented last.   Staddon also claims that these
two pieces of evidence show that there are limitations upon
animals' memories.   Given these limitations it would seem
likely that they will have a bearing on the outcome of experi-
ments on temporal control.

        Staddon (1974) says that the omission effect is a
case of 'overshadowing'.   The animal is in a situation where
two time marks have the same predictive significance, yet they
have different values for the animal.   "The animal may then
attend primarily to the less neutral stimulus.   Thus, the
temporal control by the more neutral stimulus may be selectively
impaired."   The dependence of the omission effect upon FI value,

he says, is due to the animal being able to remember N for a
short interval without impairment. A similar argument is
used to explain the magnitude effect and the effect of different
durations of blackout upon pausing, as is used for the
explanation of the omission effect. The greater the magni-
tude of the reinforcer or the longer the duration of the blackout,
the more 'value' it has for the organism, and hence the better
the temporal control produced.

It would seem from the above paragraphs that although
the evidence for Staddon's ideas on memory and attention are
still somewhat speculative, that the basic concept of the relative
proximity to reinforcement principle, for an explanation for
fixed-interval responding, is sound.

Though it is observed that the typical FI performance
is found in both rats and pigeons, which are two very different
species in evolutionary terms, it is found that in a fine analysis
of their performances there are certain differences in performance.
Lowe and Harzem (1977) found that the rate at which rats will
start responding in an interval reflects their position in that
interval, i.e. the longer the postreinforcement pause, the higher
the initial rate of responding. With pigeons, however, this
was not found to be the case. Staddon (1974) reports a difference
in the manner in which rats and pigeons are sensitive to variations
in the magnitude of reinforcement ; Staddon (1970b) found, that
for pigeons, the pause after the greater magnitude in the
intercalated condition was comparable to that following

the magnitude used in training, whereas the pause after the smaller magnitudes were shorter. With rats, on the other hand, (Lowe, Davey and Harzem 1974), the pause after the greatest magnitude of reinforcement was longer than the pause in training. To what extent these differences are actually differences between rats and pigeons, and to what extent they merely reflect the different apparatus used is not yet certain. But what is of real significance, as regards species differences, is the notable lack of them, even with two very different species like rats and pigeons.

One of the experimental variables that has been used on the fixed-interval schedule is that of punishment. Azrin and Halz (1961) trained pigeons to stability on FI 5-min, they then introduced response contingent shock intensities from 30 volts to 180 volts, used in ascending order in blocks of daily sessions. The rate of responding was found to be a decreasing function of the intensity of the shock. It was, however, found that the temporal distribution of responses in each interval of the FI was not affected by the punishment contingency, the scalloped response pattern remaining.

To conclude this section on the FI schedule of reinforcement with a summary of the major points. It would seem that the pattern of responding is a gradual acceleration in

the course of the fixed interval. The major variable for changing
the length of the postreinforcement pause and the rate of
responding is the FI value. Other variables such as punishment,
providing regular non-contingent reinforcement during the pause
and varying the magnitude of reinforcement, seem to have
relatively less effect on the postreinforcement pause. It was
argued that the main determinant of responding on FI was the
animals relative proximity to reinforcement.

Fixed Ratio.

On the fixed ratio (FR) schedule of reinforcement,
reinforcement is delivered after the last of a fixed number of
responses has been made. The typical performance of animals on
this schedule consists of a postreinforcement pause and then a
rapid transition to a high constant rate of responding (Ferster
and Skinner 1957). As with the fixed-interval schedule the
pattern of responding may be considered in two parts, the
postreinforcement pause and the rate of responding in the run time
(Powell 1970; Staddon 1972a).

Several studies have looked at the relationship between
the length of the postreinforcement pause and the FR value.
Ferster and Skinner (1957) found this to be a positive relationship,
as the ratio value was increased the postreinforcement pause got

longer. Similar findings have also been obtained by Felton
and Lyon (1966); Boren (1961) and Powell (1968). A negative
relationship between the ratio value and rate of responding in
the run time has also been reported ; Felton and Lyon (1966)
and Powell (1968) found that as the ratio value was increased
the running rate decreased. It was found that with both
postreinforcement pause and running rate that there was
considerable intersubject variation. Inspection of the section
of cumulative record presented by Felton and Lyon (1966)
suggests that this reduction in the running rate is due to
breaks in responding of several seconds during the run time at
the high ratio values, bursts of responding, of about the same
rate as is characteristic of the running rate of low ratio values,
making up the rest of the run time.

It would seem that since an animal will pause for a time
after reinforcement on an FR schedule, that it is not maximising
its rate of reinforcement. One possible explanation for this
failure to produce optimum performance could be that the animal
is fatigued after the run up to reinforcement and rests. There
is, however, experimental evidence which makes an explanation in
terms of fatigue doubtful. When two different FR values are
correlated with different extroceptive stimuli and presented in
random order within a session (a multiple fixed ratio), the
postreinforcement pause is appropriate to the forthcoming FR value

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

An alternative explanation for the occurrence of a
postreinforcement pause on fixed-ratio, which has been given,
(Ferster and Skinner 1957; Nevin 1973) is that the reinforcement
acts as a negative discriminative stimulus, as it signals a period
of non-reinforcement. Because it takes the animal time to
complete the ratio requirement, then this time will be the minimum
interreinforcement time. So, even though there are no explicitly
programmed temporal contingencies on FR, temporal factors may
nevertheless play a part.

The evidence that there is indeed a part played by
temporal factors in determining FR performance is quite strong.
Berryman and Nevin (1962) trained rats on an FR schedule, an FI
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 high rate, or could wait until the time requirement 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,
on an interval schedule or an interlocking schedule (cf Nevin
1973).

Similar effects have been reported by Killeen (1969)
using pigeons in a yoked control procedure.   In this yoked
procedure two experimental chambers are connected so that the
scheduling of reinforcement 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 'master'
subject).   In Killeen's (1969) study, the 'master' birds were
placed on different FR schedules, while the 'yoked' birds
received reinforcement on an FI-like basis, although the
intervals were not exactly constant.   There appeared to be no
difference between the postreinforcement pause of birds on the
FR schedules and the yoke control birds, though it was found
that the running rate was higher in the FR condition.

Neuringer and Schneider (1968) exposed pigeons to
FR and FI schedules, on which each response was followed by a
blackout, in order to suppress responding.   By this method they
could manipulate the interreinforcement interval in the FR
schedule, the longer the blackouts the longer was the
interreinforcement interval, and also manipulate the number of

responses that could be emitted during the interreinforcement
interval on the FI schedule. On the FR schedule the duration
of the postreinforcement pause and the post blackout latency
increased with the duration of the blackout. On the FI schedule,
on the other hand, there was no effect upon either of these two
measures with an increase in the duration of the blackouts.
Since the blackouts increased the interreinforcement interval
on the FR schedule and not on the FI schedule, and reduced
response number on the FI schedule but not on the FR schedule, it
would seem that it was the interreinforcement interval and not
the response number that controlled the pause on both schedules.

Similar conclusions may be drawn from the results of an
experiment by Farmer and Schoenfeld (1964). They devised a
situation whereby a response was only reinforced if a given fixed
amount of time had elapsed since the previous reinforcement, and
the interval separating that response from the preceding response
exceeded a specified time (a DRL contingency). This had the
effect of greatly reducing the running rate, but the duration of
postreinforcement pause was not affected. Other techniques which
have produced comparable results have been ; requiring only one
response anywhere in the interval to produce a reinforcement at
the end of the interval (Shull 1970a), and changing the unit from
a single response to a fixed number of responses (Shull, Guilkey
and Witty 1972).

From the above evidence it would seem that the important factor in determining the postreinforcement pause in the FR schedule is the interreinforcement time. However, a study by Crossman, Heap, Nunes and Alferninck (1974) seems to suggest that in some circumstances the number of responses required in the ratio may also play a part. They arranged a multiple schedule in which the first component was an FR of 25, 50 or 100 and the second component was FR2 in which the two responses were separated by a blackout. A computer recorded the interrinforcement time of the first component and then determined the length of the blackout in the second component so that it was equal to the interreinforcement time of the first component. As the ratio of the first component increased so too did the interreinforcement intervals in both components. It was found that although there was a consequent increase in the postreinforcement pause in both components, that the pause in the second component was consistently shorter than that of the first. It has been suggested though that the reason for this shorter pause in the second component was because of the different stimuli used in each component (Priddle-Higson 1976).

Since it would appear that the interreinforcement time plays a major role in determining the duration of the postreinforcement pause on an FR schedule it would be reasonable

to hypothesise that the reinforcer on FR schedules is having a similar inhibitory after-effect to that of a reinforcer on FI. If this were the case it would be expected that other phenomena associated with the inhibitory after-effect of reinforcement on FI would also occur on the FR schedule.

It has, for instance, been found that if some of the reinforcers on an FR schedule are replaced by brief stimuli, that these stimuli will also come to inhibit responding, though again an omission effect is produced (Henke 1973; McMillan 1971). McMillan (1971) investigated the effect on pigeons, randomly omitting various percentages of the scheduled reinforcements and presenting a neutral stimulus (a 4-sec time out) in lieu of reinforcement. In all instances there was an increase in the overall response rate following the omission stimulus compared to the response rate following reinforcement. This change in rate was found to be mainly due to a shorter post-stimulus pause, compared with the postreinforcement pause, rather than a change in the running rate following the stimulus. Similar effects have also been reported by Davidson (1969) using rats on a second order* schedule FR6 (FR6:S). On this schedule the

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* A second order schedule is a schedule in which the response, instead of being a single lever press is defined in terms of the completion of a second schedule requirement.

animal had to respond six times to produce a brief stimulus,
after obtaining five stimuli six more responses would produce
reinforcement in addition to the brief stimulus.   The pause
following the stimulus was found to be of a shorter duration
than the pause following the reinforcement.   Several other
studies have also presented a brief stimulus in lieu of
reinforcement, with the framework of a second order schedule,
Neuringer and Chung (1967); Blackman, Thomas and Bond (1970),
and Stubbs (1971), and found comparable results.   Staddon
(1970b) states that   :

>'The effect 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 effect of
> reinforcement, but generally of smaller
> magnitude (P230).'

Since it has been shown above that when a stimulus
is presented in lieu of reinforcement, on an FR, there is an
inhibitory effect, it would be consistent with Staddon's
statement, above, to conclude that the reinforcer also has an
inhibitory after-effect on FR schedules.

Another similarity between the properties of the
reinforcer on an FI schedule and that on an FR schedule has
been found in an unpublished study by the present author
(not presented in this thesis). Rats were trained on an
FR 40 schedule until a stable pattern of responding was
produced. Probe intervals of both different ratio values
and different fixed time values were then occasionally
introduced into the session. The pauses following both the
fixed time reinforcers and the ratio reinforcers were found
to be comparable with the postreinforcement pauses that were
found during the rest of the session. It would seem that it
is the appearance of the reinforcing stimulus on FR that
inhibits responding and that this inhibitory influence is
conditioned over several intervals, since it was shown in this
probe experiment that there was no local effect of the preceding
probe interval upon subsequent postreinforcement pause.

There are other properties of the period just after
reinforcement has been delivered on an FR schedule, that seem
to suggest that the reinforcer is having a similar effect on
behaviour on FR as it is on FI schedules. For example, it
has been shown that there appear to be aversive characteristics
related to the FR schedule, particularly during the postreinforce-
ment pause. Azrin (1961), Thompson (1964; 1965) have shown that

subjects will respond to produce time out (TO) from FR schedule

contingencies and that the amount of time spent in TO is an

increasing function of the FR requirements. Elicited

aggression has also been recorded on FR schedules (Azrin,

Hutchinson and Hake 1966; Cherek and Pickens 1970; Flory 1969;

Gentry 1968; Hutchinson, Azrin and Hunt 1969; and Knutson 1970).

For example, Azrin et al (1966) and Knutson (1970) found that

pigeons rate of attacking a target decreased as a function of

increasing time since reinforcement.

There are several differences between the pattern of

responding produced by an FR schedule and that produced by an

FI schedule. For example, it is difficult to get an animal to

respond stably on FR 300 or above (cf Zeiler 1977), but is quite

easy to get an animal to maintain a performance in which a mean

of well over 300 responses are made in the interreinforcement

interval on an FI schedule. Zeiler (1977) proposed that the

reason for this is that on FR schedules the animal is not given

the opportunity to vary the number of responses in each

interreinforcement interval. The postreinforcement pause on

FR schedules is also found to be far more sensitive to some

variables other than the interreinforcement interval, than is the

postreinforcement pause on FI schedules. The effect of punishing

each individual response on FR (Azrin 1959) greatly extends the

duration of the pause, although once responding has started the running rate was much the same as in the non-punished condition. With FI responding, punishment only slightly effects the post-reinforcement pause (Azrin and Holz 1961). Other examples of variables that would appear to have a greater effect on the FR pause as compared with the FI pause are : Deprivation (Powell 1969; 1972; Winograd 1965), as deprivation, or shock intensity, in the case of escape, goes up the postreinforcement pause is increased. With FI, on the other hand, there is only a slight change in the postreinforcement pause (Collier 1962). The introduction of a target for elicited aggression also has a disruptive effect on behaviour, in greatly extending the pause on FR, but hardly affecting its duration on FI. (Cohen and Looney 1973; Knutson 1970).

Shull and Guilkey (1975) suggest that the reason for the more sensitive pause on FR schedules is because the time to the terminal reinforcement is independent of pause time. That is to say, however long the animal pauses on FR the time remaining to next reinforcement will stay the same. With FI, on the other hand, as time goes on, the conditions become increasingly conducive to termination of the pause since the proximity to reinforcement increases with time. The above variables, they claim, may alter the favourability of conditions

during the pause relative to conditions after the pause, hence making the pause more conducive.

Taking this section on fixed-ratio as a whole it would seem that, as with FI responding, a major determinant of behaviour on FR is temporal, though there are certain differences in the sensitivity of the two schedules to some variables.

Variable Interval.

A variable interval (VI) schedule consists of a series of different minimum interreinforcement times. The schedule being generally described in terms of the arithmetic mean of the intervals making up the schedule ; for example, a schedule in which intervals of 6-sec, 10-sec, 18-sec and 30-sec were presented randomly would be a VI 16-sec. It can be seen that within this loose definition several different types of VI schedules may be generated with different rules or methods used to compose the intervals that make up the schedule. Even though two schedules have the same mean interreinforcement interval they may still have vastly different distributions.

Traditionally, VI schedules have been considered to produce a constant rate of responding through each interreinforcement interval, having little or no consistent pausing after reinforcement, e.g. Nevin (1973), also Hilgard and Bower (1966), describe the behaviour produced by a VI schedule as :

> "remarkably stable and uniform, and
> highly resistant to extinction"

Sidman (1960) says of VI schedules,

> '.....a VI reinforcement schedule, for
> example, is commonly used to generate
> a stable rate of responding, deviation
> from which will provide a measure of
> the effect of other variables'. (Pp 170 -
> 171)

As a result VI schedules have been used extensively as behavioural baselines. Dews (1958), and Ferster and Skinner (1957) have used it to study the effects of drugs on behaviour. Blackman (1967) presented a stimulus during a VI schedule which signalled on unavoidable shock and found the presentation of the stimulus suppressed responding (conditioned suppression).

Several studies have looked at the effect of varying the rate of the delivery of reinforcement upon the rate of responding on a VI schedule. These studies can roughly be

divided into three main groups.   (1) The effect of altering
the rate of reinforcement to one component of a multiple schedule.
(2) The effect upon the relative rates of responding when two VI
schedules are run concurrently and the relative rates of
reinforcement are manipulated.   (3) The effect upon the absolute
rate of responding when the absolute rate of reinforcement is
manipulated.

The effect of varying the rate of reinforcement on one
component of a multiple schedule upon the rate of responding in
both components has been investigated by Reynolds (1961).   He
originally trained pigeons on the same VI schedule associated with
two different key colours.   The schedule associated with one of
the key colours was then changed to extinction.   This produced
a drop in the rate of responding in the extinction component and
an increase in the rate of responding in the VI component.
Reynolds called this effect 'positive contrast'.   It has since
been widely reported in the literature, for example, Reynolds and
Catania (1961); Staddon (1969b) with pigeons and Coats (1972) with
rats as subjects.

A similar, though opposite, effect has also been reported
in which the rate of responding in the unchanged component of a
multiple schedule decreases following an increase in the rate of
reinforcement and subsequent elevation of rate of responding in

the other component (negative contrast). Nevin (1968) for
example, observed negative contrast in a multiple schedule in
which one of the VI 3-min components was changed to DRO
(differential reinforcement of the other behaviours).

A further phenomenon that sometimes occurs when
one component of a multiple schedule is changed, is that of
'induction'. This differs from contrast in that the change
in the rate in the unaltered component is in the same direction
as the change in the rate in the altered component. Hemmes
and Eckerman (1972), for example, trained pigeons on a multiple
VI VI, then changed one of the components to a DRH (differential
reinforcement of high rate) schedule. This had the result of
elevating the rate of responding in both components. It has,
however, been suggested by Rachlin (1973) that 'induction' is due
to ineffective stimulus control.

Schwartz and Gamzu (1977) have defined these
phenomena as follows :

> 'Positive contrast is defined as an
> increase in responding in an unchanged
> component of a multiple schedule with
> decrease in responding in the other
> component. Negative induction is
> defined as a decrease in responding in
> an unchanged component of a multiple

schedule with decrease in responding in
the other component.   Positive induction
is an increase in responding in an unchanged
component of a multiple schedule with
increase in the other component, while
negative contrast is a decrease in responding
in an unchanged component of a multiple
schedule with increase in the other
component.' (P.73)

The second group of studies involves the altering of
the relative rates of reinforcement between two concurrent VI
schedules.   There are two usual procedures that have been used
for studying this.   Either the two VI schedules are programmed
separately to different keys in a Skinner box, so that to change
schedule all the animal has to do is to change keys (e.g.
Herrnstein 1961); or the two schedules are associated with
different stimuli on a response key, the schedules being able
to be changed by a response on a second key, the change-over key
(CO-key), (e.g. Findley 1958).   The two schedules are separated
by a change-over delay (COD) which is the minimum time until a
reinforcer will be delivered after a change of schedules.   It
is found that without COD the animal will rapidly alternate between
the two schedules, (Herrnstein 1961; Skinner 1950).

When two concurrent VIs are programmed independently, separated by a COD of about 2-sec, the following relationship is generally found :

$$\frac{R\,1}{R\,1 + R\,2} = \frac{r\,1}{r\,1 + r\,2} \qquad (1)$$

Where R1 and R2 represent the number of responses emitted to each of the two component schedules, respectively, and r1 and r2 are the frequencies of reinforcement associated with each VI schedule. This relationship is known as 'matching' since it shows that the animals match its relative rates of responding on one schedule to the relative rate of reinforcement associated with that schedule.

Herrnstein (1961) demonstrated this using pigeons as subjects. The two VI schedules were programmed separately to two keys and separated by a COD. The overall rate of reinforcement was kept constant at 40 reinforcers per hour, but the proportion allocated to each key was systematically varied. Many further examples of response matching have been reported; Baum (1974a) found that he still got a matching relation using a flock of wild pigeons as subjects, they inhabited an attic in which he placed a standard operant apparatus. McSweeney (1975) programmed the VIs to treadles rather than response keys and still obtained

matching in each of his four pigeons. Schroeder and Holland
(1969) used humans as subjects in a task in which they had to
detect the deflection of a pointer on each of four dials. A
fixation on a dial after looking towards another dial counted
as a response. Looking horizontally or diagonally between the
two pairs of dials, counted as a change-over, while change in
fixation between left and right-hand dials was both, the
pointer deflections being delivered on two independent VT
schedules. Matching was again found.

Several experiments have not only looked at the relative
response rates between the two concurrent VI schedules, but have
also recorded the relative amount of time allocated by the
organism to each of the components. Catania (1963) found that
pigeons approximately matched both relative response rates and
relative amount of time spent in each component to the relative
frequence of reinforcement. In this experiment he employed a
CO-key procedure which enabled him to accurately measure the time.
Similar results have also been found by Silberberg and Fantino
(1970) and Shull and Pliskoff (1967). Thus, it is also possible
to write a second matching equation (equation 2) in terms of the
time spent responding in each component.

$$\frac{T\,1}{T\,1 + T\,2} = \frac{r\,1}{r\,1 + r\,2} \qquad (2)$$

Where T1 and T2 are the amounts of time spent responding in
each component, respectively.

It has been shown that it is not necessary for the
animal to make formal responses during the components of a
concurrent schedule for time matching to occur. Brownstein
and Pliskoff (1968) used a CO-key situation in which the food
was delivered on two independent VT schedules. They found
that the relative time spent in the presence of each stimulus,
matched the relative rate of reinforcement associated with that
stimulus.

Findings such as these, together with the finding by
Blough (1963), that when a pigeon is responding on a particular
component the rate of responding is independent of the component,
with the majority of the IRTs falling between 0.3 and 0.5 sec,
has led Baum and Rachlin (1969) to suggest that time spent
responding is the most general measure of response frequency for
relative response-like key pecking or lever pressing.

Though the matching equation (equation 1) seems to produce
a good description of response rates on concurrent VI schedules,
several experimenters (Baum 1974b; de Villiers 1977; Staddon 1977b)
have found that a better fit to the data can be provided by
equation 3 overleaf.

$$\frac{R1}{B} = K \left(\frac{r1}{A} \right)^a \qquad (3)$$

Where $\underline{B}$ is equal to the total number of responses in the situation, i.e. $(R1 + R2)$ and $\underline{A}$ to overall frequency of reinforcement $(r1 + r2)$, $\underline{a}$ and K are just empirical constants. It has, however, been pointed out by Rodewald (1978) that it is not surprising that equation 3 fits the data better than equation 1, since equation 3 has two free parameters, whereas equation 1 has none. Failure to produce precise matching could be due to either response bias or lack of stimulus control rather than anything more fundamental.

The third group of studies, which is concerned with the effect of frequency of reinforcement upon the rate of responding, deals with the effect varying the frequency of reinforcement within a single VI schedule. Though this is the most basic of the three groups of studies, it is only recently that it has been dealt with in a quantitative way. Herrnstein (1970; 1971) extended the matching equation (equation 1) to take account of a single response situation.

Equation 1 shows that the rate of responding to each alternative, in a concurrent VI situation, is proportional to the relative frequency of reinforcement for that alternative. This may be expressed mathematically as follows.

$$R_1 = \frac{k \times r_1}{(r_1 + r_2)} \qquad (4)$$

Where k is the constant of proportionality. If, however, there are n alternative responses and subsequent sources of reinforcement, equation 4 would then become

$$R_1 = \frac{k_1 \times r_1}{\displaystyle\sum_{i=o}^{n} r_i} \qquad (5)$$

In a single response situation only one source of reinforcement is specified, other sources of reinforcement are assumed to be constant for a particular situation of drive, experimental apparatus and subject. With this assumption it is possible to further simplify equation 5 to :

$$R_1 = \frac{k \times r_1}{r_1 + r_e} \qquad (6)$$

Where r_e is the sum of all unspecified sources of reinforcement, which is expressed in the same units as r_1. Similarly, the constant k is expressed in the same units as R_1, i.e. responses per unit time and is taken as the asymptotic rate of responding that would occur if r_1 was the only source of reinforcement.

Herrnstein (1970) used data taken from an experiment
by Catania and Reynolds (1968) in which six pigeons were exposed to
VI schedules ranging in their frequency of reinforcement from
8 to 300 reinforcers per hour.   The least squares fit to
Equation 6 (Herrnstein's equation) of this data for each of the
pigeons ranged between 76.7 - 99.8% of the data variance.   The
values of k and re ranging between 66.3 - 113 and 4.51 - 291,
respectively.

The generality of Herrnstein's equation in its ability
to account for other situations in which the rate of reinforce-
ment is varied has been tested (de Villiers and Herrnstein 1976
and de Villiers 1977).   The equation seemed to account very
well for the data produced in an early experiment by Crespi
(1942), in which rats were run down an alley for different
weights of dog food.   Herrnstein's equation described the
relation between the quantity of food and the mean running
speed for each group of rats, accounting for 99.6% of the
variance in running speed.   This equation is not then just
confined to the discrete response situation and also not just
to variations in the rate of delivery of reinforcement but to
overall amount of reinforcement.   This latter point was again
demonstrated in experiments by Davenport, Goodrich, and Hagguist
(1966), who used various magnitudes of reinforcement for monkeys

lever pressing on a VI 60-sec and Hutt (1954) who varied the
magnitude of reinforcement for rats on a VI schedule, the data
from both these experiments fitting the equation.

The equation also seems to account for negative
reinforcement. De Villiers (1974) shocked rats on a VT basis,
if, however, the rats made a response in the interval between
two shocks, the next shock was cancelled. The equation
accounted for the increase in the rate of responding as the
number of avoided shocks increased.

It has been shown that the equation can take account
of many situations and methods of reinforcement and, as a
result, has been put forward as a model of response strength
(Herrnstein 1970; de Villiers 1977). There are, however,
some schedules in which Herrnstein's equation does not seem to
fair so well. For example, it has difficulty in describing
the relation between overall rate of responding on a fixed-
interval schedule, and the frequency of reinforcement on that
schedule (de Villiers 1977). If, however, instead of the
overall rate being used, the running rate, or the rate after the
break-point, and instead of the FI value, the mean run time is
used to calculate the frequency of reinforcement delivery, the
equation seems to account for the data far better. This

finding could be due to the elimination from the data of the
inhibitory influences of the reinforcer.

So far this review of VI performance has only been
concerned with variations in the overall rate of responding
across conditions, without giving consideration to any variation
in rate that may occur within the interreinforcement interval.
It was noted by Ferster and Skinner (1957) that the different
distributions of intervals making up a VI schedule produced
different response patterns within the interreinforcement
interval.   For example, they found that the addition of several
extra short intervals to a VI, increased the rate of responding
in the early part of the interval and decreased the postreinforce-
ment pause.

The major different VI schedules that have been described
in the literature are as follows : (1) Arithmetic VI schedules;
in this schedule any interval is the same value as the next
shortest interval plus a constant.   (2) Geometric VI schedules;
in this schedule any interval is the value of the next shortest
one multiplied by a constant.   (3) Fibonacci VI schedule; in this
schedule any interval is the sum of the next two shortest intervals.
(4) Linear VI schedule; in this schedule the probability of a
response being reinforced at a particular interval after

reinforcement increases linearly with time since the last
reinforcement. (5) Constant probability VI schedules ; in
this schedule the probability of responses being reinforced remains
constant as time since the previous reinforcement increases.
There are two main ways of designing constant probability VI
schedules. In one method the difference between the intervals
is held constant while the relative frequencies of different
intervals is varied (e.g. Farmer 1963; Millerson 1963). The
other method holds constant the relative frequency of different
intervals but varies the difference between successive intervals
(e.g. Catania and Reynolds, 1968; Fleshler and Haffman, 1962).
(6) Random interval (RI); this schedule is similar to the
constant probability VI in that the probability of reinforcement
remains constant, though its construction is different; there is
a constant recycling time interval. T, the first response at
the end of this interval T will be reinforced with a probability
of P, thus the average interreinforcement time will be $\frac{T}{P}$.

Catania and Reynolds (1968) studied the different
patterns of responding produced by the different VI schedules.
Their main dependent variable was the local rate of responding
across the longest interval in the schedule. Five different
VI schedules were compared, each providing roughly the same
overall rate of reinforcement, but with different distributions

of intervals. One of the schedules was an arithmetic VI, two of the other four were arithmetic VIs with extra short intervals, the fourth was a linear VI and the fifth was a constant probability VI schedule.

On the arithmetic VI schedule, the probability of a response being reinforced increased with a positive acceleration with successive opportunities for reinforcement.* With the arithmetic VIs with the extra short intervals, on the other hand, there was a higher probability of reinforcement soon after the previous reinforcement than there was at later times since reinforcement. The addition of the short intervals seemed to produce a higher rate of responding in the early part of the interval, followed by a decrease in rate. This effect was more pronounced in the schedule with the most extra short intervals. The ordinary arithmetic VI, on the other hand, had a local rate of responding that increased with time since the last reinforcement. It would seem from this that the high rate at the beginning of the extra short interval schedules was due to the increased probability of reinforcement at that point. Similarly, the increasing rate of responding in the arithmetic VI would seem to correspond in

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* An opportunity for reinforcement occurs on a VI schedule at the end of each interval. Therefore, if a VI is made up of intervals 5-sec, 10-sec, 15-sec and 20-sec, then there will be an opportunity for reinforcement at 5-sec, 10-sec, 15-sec and 20-sec after the last reinforcement.

direction to the increasing probability of reinforcement in that
schedule.

With the linear VI schedule used by Catania and
Reynolds there were only five intervals making up the schedule,
resulting in only five discrete times after reinforcement at
which reinforcement could be made available ; but the
probability at each of these successive opportunities for
reinforcement increased more rapidly than it did with arithmetic
VI.   The pattern of responding on this schedule, as with the
arithmetic VI, consisted of a gradual increase in the rate of
responding as the time since the previous reinforcement increased,
for three out of four pigeons.   The performance of the fourth
pigeon was somewhat idiosyncratic, in that its local rate
increased to a peak and then declined.   With the constant
probability VI it was found that the rate of responding seemed to
remain roughly the same throughout the whole of the long interval,
for all four pigeons.

The conclusion that can be drawn from these results is
that the local rate of responding is in some way determined by the
probability of reinforcement at a particular point in time after
reinforcement.   The problem with using probability of reinforcement
as a measure is that it is only above zero at discrete times after

reinforcement or opportunities for reinforcement. Accordingly, this analysis takes no account of the time between successive opportunities for reinforcement, which may vary. For example, Ferster and Skinner (1957) ran both geometric and fibonacci VI schedules, in which the probability of reinforcement increased with successive opportunities for reinforcement. For both of these schedules, Ferster and Skinner's cumulative records showed that the local rate of responding decreased with time since the previous reinforcement. Catania and Reynolds (1968) argue that something more than the probability of reinforcement alone must be taken into account in the analysis of performance within intervals of VI schedules. They propose as an alternative the 'local rate of reinforcement'. This measure is based on the premise that effects of a given probability of reinforcement at a given opportunity for reinforcement may spread over time and may depend on the closeness in time of other opportunities for reinforcement. The effect of a given probability of reinforcement is arbitrarily taken as having influence up to the midpoint between that particular opportunity for reinforcement and the previous and subsequent ones.

They found that this measure produced a much better description of their data. The change in the rate of responding corresponded to the change in the local rate of reinforcement, though changes in the local rate of reinforcement are large in comparison

with the changes in the local rate of responding. Catania and

Reynolds suggest that the reason why there is not more precise

matching between these two variables is because the rate of

responding will have met its asymptotic maximum rate when the

rate of reinforcement is 50 per hour or more (cf Herrnstein 1970).

Catania and Reynolds (1968) did not take a measure of

postreinforcement pause, though there is evidence that the duration

of the pause is far in excess of the time necessary to consume

the reinforcer on a VI schedule (Harzem, Lowe and Priddle-Higson

1978). The factors determining the postreinforcement pause on VI

have received some attention. Lachter (1971), 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 pause was an increasing function

of the ratio $\frac{T}{P}$. It would also be a function of the interreinforce-

ment interval T which could be a more salient variable than the

ratio $\frac{T}{P}$, as the reinforcement will also signal a period of

non-reinforcement T. Martin (1971) has shown a similar relation-

ship between the postreinforcement pause and $\frac{T}{P}$ when T was held

constant at 30-sec and P was varied. Similarly, Farmer (1963)

varied both P and T and found again that the postreinforcement

pause was a function of $\frac{T}{P}$. From these results it is not possible

to conclude which variables are the most salient in determining

the pause, since when either T or P are varied then $\frac{T}{P}$ (the

RI value) also varied, which itself may be a critical factor.

It is, however, possible to conclude from Martin's (1971)

results that T alone is not the critical variable in

determining the pause since, when T was held constant, the

pause could be still caused to vary by manipulating P.

There is a certain degree of evidence to suggest that

the underlying factor determining the postreinforcement pause

on VI is, as with FI and FR, inhibitory temporal control.

If, for example, a neutral stimulus is substituted for some

of the reinforcements on a VI schedule, they will also inhibit

responding for a time after their occurrence. The pauses

following these neutral stimuli are of a shorter duration than

the pauses following food, which is the omission effect,

(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 colour), the post-omission pause tended to be

longer than when reinforcement omission was unsignalled, although

it was still shorter than the postreinforcement pause.   These

findings are similar to those reported when reinforcements are

omitted on FI schedules (cf Keller 1972; Staddon and Innis 1966;

1969).

It is also found that the inhibitory after-effects
of reinforcement on VI, as with FI and FR, is a function of
the reinforcement magnitude ; Campbell and Seiden (1974)
varied the magnitude of water reinforcement and found a longer
pause for higher magnitudes of reinforcement (see also Harzem,
Lowe and Priddle-Higson 1978).   Further evidence for the
inhibitory after-effect of reinforcement on VI comes from a
study by Dove, Rashotte and Katz (1974) who found that the
attack rate of pigeons on a constant probability VI was a
function of the mean interreinforcement interval, the attacks
occurring mainly in the postreinforcement pause.

In summary then, it would seem that there are two
major factors in determining performance on a VI schedule.
First, the absolute rate of reinforcement, whether this is
expressed in terms of frequency of the delivery or in terms of
the magnitude of the delivery, seems to determine the absolute
rate of responding in a quantifiable way according to
Herrnstein's equation.   Secondly, the distribution of the
intervals making up a VI schedule seem to determine the local
rate of responding within each interreinforcement interval.
Since the temporal separation between successive opportunities
for reinforcement is a critical factor it would seem that time,
as with FR and FI, plays a major role in determining behaviour.

Catania and Reynolds (1968) suggest that VI schedules may be placed on a continuum of the degree to which temporal factors effect the subjects behaviour ; they express this as follows :

> 'The FI schedule is at one extreme of a
> continuum of schedules that differ in
> the degree to which they allow discriminative
> control by time since reinforcement ; at
> the other extreme is the constant-probability
> VI schedule, which simplifies performance
> by eliminating the temporal patterning of
> reinforcement as a controlling variable
> (P.357).'

Variable Ratio.

In a variable ratio (VR) schedule the number of responses required to produce reinforcement varies between interreinforcement intervals, the schedule is usually described in terms of the arithmetic mean of the number of responses required to produce reinforcement in all the interreinforcement intervals of a session. As with VI schedules the distribution of ratio values can be varied while the mean ratio value remains fixed. In most VR schedules successive ratios are usually selected, in irregular order from a set of ratios derived by a particular mathematical progression, i.e. arithmetic VR or geometric VR.

An alternative way of producing a VR schedule is to assign a particular probability P for each response being reinforced, this method produces a random ratio (RR) schedule.

The VR schedule as with the VI schedule has frequently been regarded as generating a constant and high rate of responding ; with no consistent pauses occurring after reinforcement (Nevin 1973; Staddon 1972a). A more extreme view is taken by Hilgard and Bower (1966) who in describing VR schedules, state that :

> 'The pause after reinforcement may be
> eliminated by adopting variable ratio
> reinforcement, that is, using a range
> of ratios around a mean value. (P.117)'

The performance produced by RR schedules has, in general, only been considered in terms of the overall rate of responding. For example, Brandauer (1958) exposed pigeons to a series of RR schedules arranged in order of descending probability of reinforcement for each response, P, ranged from 1.0 (CRF) to 0.00167. He found that over a moderate range overall response rates increased, as P got smaller, to $P = 0.02$ for one subject and to $P = 0.01$ for another. Similar effects of increasing the ratio value has also been reported by Kelly (1974) using monkeys, however, Sidley and Schoenfeld

(1964) in a between group design study found little relationship
between response rate of reinforcement probability (ratio value).

A study by Kintsch (1965) analysed the performance of
rats on a VR schedule. He found that on a VR15 there was a
postreinforcement pause of about 2-3 sec followed by an abrupt
transition to a high, approximately constant, rate of responding
until the next reinforcement. Farmer and Schoenfeld (1967)
analysed separately the effect of increasing the probability of
reinforcement on the postreinforcement pause and the running rate.
They found that the postreinforcement pause increased as a function
of the decrease in the value of P. The running rate, on the other
hand, did not vary systematically as P was decreased. They
concluded that on RR schedules :

> 'These measures (postreinforcement pause and
> running rate) do not necessarily co-vary
> so that combining them with a single index
> may mask certain effects of reinforcement
> probability variable. (P.173)'

Attempts to produce a quantitative description of the
variation in rate of responding on VR with variations in ratio
value have not been very successful. Pear (1975) suggested the
following modification of Herrnstein's equation to take account
of VR schedules.

$$R = k - nre \qquad (7)$$

Where the symbols R, k and re are the same as in Equation 6, and n is the VR schedule value. It can be seen that this equation predicts a systematic decrease in rate with increase in n, which does not seem to be born out by the results of the above studies. Equation (7) does, however, have the virtue of predicting that when the ratio value (n) gets sufficiently large, so that nre = k, responding will stop altogether. This is a common finding (e.g. Ferster and Skinner 1957).

It has been suggested (Priddle-Higson 1976), that as with the other three schedules, so far discussed, that the reinforcer may have inhibitory after-effects. The reinforcer on an RR cannot be said to signal a period of non-reinforcement, as the first response after reinforcement is just as likely to be reinforced as a response anywhere else. The reinforcer will only be delivered for the first response very infrequently compared with the number of times it will be delivered for subsequent responses. In this case reinforcement is associated with an absence of reinforcement for the majority of intervals, as a result it could come to develop inhibitory after-effects. It may be argued at this point, of course, that a response is also associated with an absence of reinforcement just as much as a reinforcer, therefore, it too should develop inhibitory

after-effects. However, the counter-argument could be brought, that the reason why this does not occur is because reinforcement is a far more salient stimulus, having a much greater inhibitory influence (cf Staddon 1974).

Further evidence for the inhibitory after-effects of VR reinforcement comes from a study by (Priddle-Higson, Lowe and Harzem 1976). It is, for example, found that the postreinforcement pause on a VR schedule was a positive function of the reinforcement magnitude, the effect being enhanced on large VR values, and that there was an omission effect when some of the reinforcers were replaced by a neutral stimuli in lieu of reinforcement. Other more indirect evidence comes from the findings of a study by Webbe De Weere and Mabgodi (1974) that schedule induced aggression occurs in VR schedules, but only following reinforcement.

It would seem that even in an RR schedule where there is no explicit temporal contingency, that time still exerts an influence on the pattern of responding.

Summary.

It would seem that on all four basic schedules of reinforcement that the pattern of responding observed consists of a postreinforcement pause, followed by a run of responding until the next reinforcement. There is evidence to suggest that the main determinant of the postreinforcement pause in the two schedules in which reinforcement is presented regularly, fixed interval and fixed ratio, is the interreinforcement interval (cf Neuringer and Schneider 1968; Killeen 1969). Determination of the postreinforcement pause on the two irregular schedules, variable interval and variable ratio, does not seem to be so well understood. It would seem from the work of Lachter (1970), Martin (1971) and Farmer (1963) on random interval schedules, that two possible controlling variables are, the duration of the shortest interval (T), and its probability of occurence (P). It would also seem likely that the postreinforcement pause is only a function of the shortest few interreinforcement intervals making up the VI schedule, since it was shown by Catania and Reynolds (1968) that the local rate of responding in a particular region of an interreinforcement interval depends upon the local rate of reinforcement in that region. Therefore, if there was a high rate of reinforcement soon after reinforcement, an animal would be expected to respond, if there was a low local rate of reinforcement, then the animal would be more likely to pause.

This finding of Catania and Reynolds would also seem to be the best description of variation in the local rate of responding across an interreinforcement interval. At a more molar level, Herrnstein (1971) has shown that a functional relationship exists between the absolute rate of responding and the absolute rate of reinforcement.

Further work will have to be done for a more complete understanding of the controlling variables on irregularly temporally defined schedules. Answers to questions such as, the degree to which the shortest interval in the VI affects the duration of the postreinforcement pause, whether the mean interreinforcement interval has an effect upon the pause, and to what extent temporal factors play a part in determining behaviour once responding has started. These questions can probably be best answered in the first instance by an investigation of the most basic irregularly temporally defined schedule, the two-valued mixed FI. This schedule has the advantage of having a limited number of possible controlling variables whilst still retaining the basic features of a VI schedule.

One factor, though, that must be having an influence upon the performance of animals on schedules of reinforcement is the animals' ability to judge time intervals. It is, therefore, proposed in the next chapter, to review the recent literature on the psychophysics of animal timing.

CHAPTER 3

THE PSYCHOPHYSICS OF ANIMAL TIMING
(A SELECTIVE REVIEW).

Introduction.

All behaviour must necessarily occur within a temporal
context. In any learning situation the ordering of events is
crucial. The conditioned stimulus must be presented before the
unconditioned stimulus if it is going to be conditioned to elicit
a response. In most schedules of reinforcement a response must
be made before reinforcement is given, and even in fixed time

schedules there is a regularity of behaviour through the interval (Killeen 1975; Staddon and Simmelhag 1971, and Staddon 1977). It was shown in the last chapter that one of the main variables affecting the duration of the postreinforcement pause and subsequent behaviour was temporal. So, for a full understanding of effects upon behaviour of schedules of reinforcement, it will be necessary to also understand the effects of time upon behaviour.

The present chapter is a review of the recent literature on the psychophysics of animal timing. It will attempt to throw some light onto such questions as the degree to which animals are sensitive to small changes in duration for which a stimulus is presented, and to what extent the basic psychophysical laws hold for time.

Temporal Sensitivity.

One of the major areas of interest in psychophysics is the study of how sensitive subjects are to small changes in the intensity of stimulation. Accordingly, the psychophysics of time studies have been concerned with the sensitivity of subjects to small changes in stimulus duration. An early example of this is a study by Cowles and Finan (1941), who trained rats in a Y-maze. The animals were held in a compartment for either 10 or 30-sec.

Running to a particular arm of the maze was then reinforced depending on the preceding time interval. It was found that the animals ran to the appropriate arm of the maze for the different durations.

Recent work has suggested that animals are capable of much finer discriminations. A study by Reynolds and Catania (1962), using a maintained generalisation technique suggests that pigeons can discriminate a change of 3 sec in 30. Stubbs (1968), in an experiment that will be described in detail below, found that pigeons could discriminate between stimulus durations of 5 and 6 seconds with above chance level of accuracy. An experiment by Nelson (1974) tested the ability of pigeons to discriminate the duration of their previous interresponse times. The birds responded on the centre key of a three key array. Each response was recorded with respect to the preceding interresponse time. Occasionally, a response turned on the two side keys, at the same time darkening the centre key. A response on one of the side keys would then be reinforced if a short interresponse time has just occurred, alternatively a response on the other side key would be reinforced if a long interresponse time had just occurred. The long interresponse time was the same across all conditions 5 - 7 sec, the short interresponse time varied. Nelson found that all four pigeons would discriminate the different interresponse

times, the finest discrimination being between 4 and 5 seconds.
The accuracy of choice depended upon the degree of similarity
between the long and short interresponse time.

A further study of particular relevance to this present
thesis was performed by Rilling (1967). Pigeons responded on the
centre key of a three key array, on one of two fixed-interval
values. The first response after the interval had finished
turned off the centre key stimulus and turned on the two side key
stimuli. Responses to one key were reinforced after a standard
interval of 45-sec, responses to the other key were reinforced if
the interval was less than 45 seconds. If an inappropriate
response was made the reinforcement was delayed by 60-sec, all the
intervals were thus initiated by the presentation of reinforcement.
The short interval was adjusted until the birds choice accuracy
was between 80 and 90 percent. Rilling found that two of his
birds reached this criterion with lower intervals of 30 seconds,
the other bird had a lower interval of 36 seconds.

Quantification of Temporal Sensitivity.

From the above paragraphs it can be seen that animals
are able to discriminate changes in the duration for which a
stimulus is presented. Further work in the field of temporal
psychophysics has attempted to quantify sensitivity into the form
of a law, which would cover all temporal discrimination situations.

Poisson Timing.

There seem to be two major theoretical alternatives as to the form this law will take. Creelman (1962) proposed the counter model. The assumption behind this being that timing is based on the counting of a random pulse of impulses. The subjects internal representation of the duration of a stimulus depending on the number of pulses that were counted during the stimulus presence. Mathematically, this would mean that repeated estimates of the same interval would result in a Poisson-distributed random variable of estimates. This Poisson distribution has the property that the variance of the distribution will always be directly proportioned to the mean of the distribution. Hence, the standard deviation of the distribution would be proportional to the square root of the mean of the distribution. This model has got some empirical backing in work on humans. Creelman (1962) performed a series of experiments in which the ability of human subjects to discriminate between durations of auditory signals was measured ; he found that the counter model applied over a range between 0.25 sec and 0.8 sec. Other studies have also found support for the model ; Abel (1972) investigated humans ability to discriminate a different duration of noise bursts, the subjects compared two durations, one of which was adjusted until the subjects performed at 75% accuracy over trials. Abel found that the counter model held for durations less than

about 0.1 sec. Kinchla (1970), using pigeons as subjects found that the counter model held for auditory temporal discrimination over a range of 1 to 8 sec.

Weber's Law.

The other alternative model of temporal sensitivity is that of Weber's law. This classical psychophysical law, when applied to temporal discrimination, implies that the degree of discriminability produced by a change in the standard duration is a constant proportion of the duration. The mathematical implication of this law is that repeated estimates of the same standard duration will result in a normally distributed sample of estimates, the standard deviation of this distribution increasing proportionally to the mean of the distribution, and, therefore, the coefficient of variation would be a constant for any given discrimination criterion.

Weber's law has been found not to apply to the result of studies of human temporal discrimination except over a very narrow range. Blakely (1933); Getty (1975); Stott (1935) have reported that the Weber fraction is a broad U-shaped function of duration, appearing approximately constant between 0.5 and 2.0 seconds, and then increasing outside these limits. With animals, however, Weber's law appears to hold much better. A study by

Church, Getty and Lerner (1976) addressed itself to the problem of which of the two theoretical alternatives applied best. They used rats in a choice situation ; the animals were presented with an auditory stimulus of either a standard duration or longer than the standard duration. Reinforcement was given if the animal made a response on the left lever after the standard duration or on the right lever after the longer duration. The longer duration was continually adjusted until the choice accuracy was 75%. The standard durations used were 0.5, 1, 2, 4, and 8 seconds. Church et al reported that the data fitted the Weber model significantly better than the counter model. Weber's law held between 2 and 8 sec, but not when the standard duration was 1-sec or less. However, Church et al point out that all the data may be described by the generalized version of Weber's law $\Delta T/(T+a)=k$ (e.g. Guilford 1954); the constant a, being independent of duration, having its greatest effect at low values, and is generally taken to be reflecting sensory noise.

Further evidence in support of Weber's law comes from a study by Tarpy (1969). In order to escape shock rats had to press one of two levers, one lever turned the shock off after a standard delay of T-sec, the other lever turned the shock off after T^2-sec. Twenty eight different groups were used each being tested on a different standard T value. Tarpy found that for the animals to chose the shortest duration 75% of the time the

the difference between the two durations was proportional to the standard duration.

Platt (1979) has looked at the application of Weber's law to temporal differentiation schedules*. He proposes that since, for Weber's law to hold, the standard deviation of the distribution of response estimates should be linearly related to the mean of the distribution, the following equation should fit the data,

$$SD(T) = a + bT \qquad (8)$$

where $\underline{a}$ and $\underline{b}$ are empirical constants, if the Weber model was applicable. The values of $\underline{b}$ would be expected to be about 0.3 and $\underline{a}$ usually to be approximately zero. Platt (1979) used data from various temporal differentiation procedures to test how well it fitted Equation 8. Though he could not find any evidence for Weber's law being able to be applied to data from a DRL schedule, he did find quite good fits with data from a DRLL procedure

* 'In differentiation schedules reinforcers are presented when a response or a group of responses displays a specified property. For example, responses might have to be emitted with a particular force, duration or form (topography) or to occur in a certain locus.' (Zeiler 1977 P.203)

(Catania 1970), differential reinforcement of lever holding
(Platt, Kutch, and Bitgood 1973) and differential reinforcement
of ratio duration and latency, (De Casper and Zeiler 1974; 1977),
described below.

Probably the most influential experiment in giving
support to the application of Weber's law to temporal discrimination
is that of Stubbs (1968). Pigeons initiated a stimulus duration
by pecking the centre key in a three key array, which changed the
stimulus on the key from yellow to white, this stimulus then
remained for a predetermined period of time after which it was
turned off automatically. There were ten discrete durations :
1, 2, 3, ...10-sec, varying nonsystematically from trial to
trial. A response on one of the side keys was then reinforced
if the duration had been between 1 and 5 sec, and on the other if
the duration was between 6 and 10 sec. Stubbs found that the
percentage of long responses increased, according to an
approximate ogival function, truncated at 10-sec, as the stimulus
duration increased. The birds made very few long responses for
stimulus durations of 1, 2 or 3 sec, but for durations longer than
this there was a steady rise in the proportion of long responses,
as the length of the duration increased.

In a further experiment Stubbs (1968) used the same
procedure for durations ranging between 2 and 20 sec and between
4 and 40 sec. Again the dividing line between long and short

durations was the midpoint of the range in each case. He again
found a truncated ogival function relating the percentage of long
responses to the duration of the stimulus. The similarity
between the functions was such that if all three were plotted on
a time scale proportional to the range of intervals used in each
condition, the curves were found to be virtually identical.
This showed that the animal's discriminative was directly related
to the size of the intervals to be discriminated, which is what
would be predicted by a Weber model of animal temporal
discrimination.

In a later experiment Stubbs (1971) used a free-operant
psychophysical procedure to compare Weber Fractions over a wider
range than had been tested before. Pigeons were placed in a two
key Skinner box, one key being the response key and the other key
being the change-over key. Each session contained a series of
stimulus time periods ; at the beginning of each time period the
response key was orange and the change-over key was blue, a
response on the change-over key changed the stimulus on the
response key from orange to green. Only one response on the
change-over key could be made after which the stimulus was turned
off and the key became inoperative. The birds were intermittently
reinforced for responding to the orange stimulus for the first
half of the duration, and for responding to the green stimulus
during the second half of the duration. Reinforcement was

followed by a 12-sec blackout, after which the key stimuli were presented again, starting a new interval. If, however, reinforcement was not presented, a 15-sec blackout was presented at the end of the stimulus duration.

Stubbs used this procedure with different time periods ranging from 15-200 sec, the periods were divided into tenths, to enable comparison across different durations. He found that the probability of a green response increased according to an ogival function with succeeding tenths of the interval. The curves from each condition were again very similar. There was in all cases a tendency to change from orange to green slightly before the midpoint of the duration.

The times at which there was a probability of 0.25, 0.50 and 0.75 of the bird making a green response were calculated from the data. The 0.50 probability was analogous to the point of subjective equality (T) of classical psychophysics. The differences between the points of probability of a green response of 0.25 and 0.75, being analogous to the interval of uncertainty being an estimate of discrimination sensitivity. Half of this value gives the difference limen and hence the value $\triangle$T. Stubbs found that the Weber fractions $\left(\dfrac{\triangle T}{T} \right)$ that were calculated from these results were not constant over the entire range of

intervals used, but increased as the durations got longer, showing that Weber's law tends to break down at large time intervals.

From the above, it would seem that Weber's law is the best approximation for a quantified description of temporal discrimination. It does, though, seem to fail at both high and low time intervals, where the Weber fraction increases, producing a U-shaped function, but within a range of 1 sec to about 20-30 sec, the fraction remains fairly constant.

The Power Law.

The next question to be discussed is the relationship between the mean of an animal's estimation of a time interval and the duration of that time interval. This is a fundamental question since it has been taken by some authors as reflecting the animal's subjective impression of the time interval (cf Killeen 1975).

Studies of human time estimation have consistently produced a power relationship between the actual time interval and the subject's estimation of that interval. Catania (1970) reviewed several experiments in which human subjects had as their task the estimation of time intervals, he found that subjects consistently overestimated short intervals and underestimated long intervals.

Eisler (1976) in summarising the results of many years' of research
on human temporal judgment came to the same conclusion, that human
time estimation was a power function of the actual duration and
that the mean of the exponent of the power and function was 0.90.
(see also Eisler, 1975)

With animals, several investigators have looked at the
effect of varying the requirements of temporal differentiation
schedules upon an animal's behaviour.   The temporal differentiation
schedules require that some aspect of an animal's behaviour should
have a precise temporal characteristic for reinforcement to be
delivered.

The most widely studied temporal differentiation schedule
is the differential reinforcement of low rate, or DRL schedule.
This schedule specifies that reinforcement will be delivered only
if the interresponse time is greater than a minimum duration.
A typical performance of a rat performing on this schedule would
consist of a pause after reinforcement, if this pause is longer
than the DRL value the first response will produce reinforcement
and the animal will tend to pause again.   If, however, the pause
is less than the specified DRL value the first response will not
be reinforced, and the animal will then tend to produce a burst of
responses before producing a comparable IRT to the schedule
criterion, (cf Harzem, Lowe and Davey 1975; Kramer and Rilling 1970).

This pattern of behaviour results in a bimodal distribution of
IRTs, with a lot of short IRTs resulting from the bursts of
responses as well as distribution IRTs around the point of
criterion, with very few IRTs in the middle region between the
two modes.   This bi-modal distribution presents problems for the
use of the mean IRT, which would be an IRT value that would
virtually never occur.   To get round this problem Catania (1970)
used the median of the modal IRTs from data that was produced in
a study by Malott and Cumming (1964), who trained rats on various
DRL values ranging from 1-sec to 100-sec.   Catania found that the
relationship between the modal IRT and the DRL value could be
described by the following equation :

$$T = 1.3t^{0.9} \qquad\qquad (9)$$

This is a power function in which t is the DRL value and T is the
median of the modal IRT.

Catania also found a similar function relating median
of the model IRT to DRL value, for data taken from a study by
Staddon (1965) who used pigeons as subjects.   They were trained on
DRL values ranging from 5.68 sec to 31.5 sec, (see also Richardson
and Loughhead 1974).

Catania (1970) himself used a schedule that did not
produce the bursts of short IRTs after an unreinforced response.

This was a differential reinforcement of long latencies (DRLL) schedule, which is a discrete trials version of the DRL schedule. Each trial began with the illumination of a response key and ended with a response on the key. If the time from the beginning of the trial to the response (T-sec) was greater than a minimum duration (t-sec) then reinforcement was delivered. The trials were separated by a 20-sec intertrial interval during which the key went dark. The values of t that were used ranged from 0.6 sec to 48 sec. He reported that the relationship between the mean latency and the minimum latency required for reinforcement was again found to be described by a power function.

$$T = 1.6t^{0.8} \qquad (10)$$

This is similar to Equation 9 for DRL. The animals seem to over-estimate small values of t and underestimate large values of t. The area in which the estimates of t are correct is about t = 10 sec, which is the indifference interval (e.g. Woodrow 1951).

Other temporal differentiation schedules have been studied, for example, differential reinforcement of lever-holding, (Platt, Kuch and Bitgood, 1973). The authors argue that this schedule has the advantage of avoiding contaminating control by elapsed time with reinforcement frequency effects. With the DRL and DRLL schedules, it could be argued the long IRTs, or latencies were due to extinction beginning to take effect, owing to the fact that the

preceding IRTs or latencies were of insufficient duration to produce reinforcement. It could not then be assumed that the long values of T were due to temporal discrimination. With the lever holding paradigm, due to the nature of the response this criticism would not be applicable. Platt et al (1973) also argue that lever holding is a more homogeneous behaviour than either latency or IRT, which simply specify what the animal should not do.

Two different procedures were used ; a free operant and a discrete trial. In the free operant procedure the rat was free to make a response at any moment in time, if the lever response was of a duration greater than the specific minimum the animal was reinforced. This procedure resulted in a high proportion of short response lengths, giving it the same disadvantages that had previously been encountered with DRL, i.e. bursts.

In the discrete trials procedure this problem did not occur. Trials began with the extension into the chamber of a retractable lever, the animal could then press for a duration T, when the lever was released it was immediately retracted and reinforcement was delivered if the duration of the lever press had exceeded a minimum duration. The minimum durations employed in this procedure ranged from 0 to 6.4 seconds.

Again it was reported that this procedure showed a power relation between the median response length and the minimum duration. The mean of the least squares fit was :

$$\overline{T} = 1.3t^{0.92} \qquad (11)$$

It was also reported that there was a general inverse relation between the constant k and the exponent n, but this was not perfect.

A final example of a temporal differentiation schedule that has been looked at is that of differential reinforcement of ratio duration and latency. In this schedule a minimum time is allowed for the completion of the whole, or a part, of a fixed-ratio requirement. In an early experiment De Casper and Zeiler (1974) made reinforcement dependent on pigeons completing a ratio component in a time greater than a specified duration. The fixed-ratio value was held constant at FR30, the minimum time to complete the ratio was varied over a range between 16 sec and 100 sec. The ratio time was found to be a power function of the criterion time. The constant k varied between 2.2 and 3.3 and the exponent n between 0.67 and 0.75, with a perfect inverse relation between the two.

In a further study by De Casper and Zeiler (1977) in which there was a minimum time criterion on the postreinforcement pause or on the run time, it was also reported that there was a power relation between these measures and the criterion time.

There are many other reports in the literature on operant behaviour where a power function describes the relation between an organism's behaviour and the value of a temporally based schedule of reinforcement. Sidman (1953), for instance, suggested that the relationship between the rate of a rats responding on an avoidance schedule and the response shock interval could be described by a power function. Another example comes from the literature on concurrent schedules, Stubbs, Pliskoff and Reid (1977) found that the relationship between an animal changing from one stimulus to another and going back to the first, and the change-over delay (COD), was described by a power function.

Given the above evidence for the generality of the power function in describing the relationship between an animal's behaviour and the temporal properties of the reinforcing environment some authors have argued (cf Killeen 1975) that an animal's internal representation of time is a power function of actual time.

Other authors (e.g. Gibbon 1977 and Platt 1979) have put a different interpretation on the results of the temporal differentiation experiments. They argue that the power function that is found is merely an artifact of the paradigm used. Because the animals are never actually reinforced for a response duration that exactly matches the criterion, but always for durations longer than the criterion, they claim that it is not justified to use the schedule values in an equation proporting to show animal timing.

They say that what should be used for the value of t in the equation
is the mean reinforced duration of response ; when this is done the
relationship is found to be linear.   To support this claim
Gibbon (1977) argues that the postreinforcement pause on fixed-
interval schedules is a linear function of the FI value.
Accordingly, on FI, the animal will experience the schedule value
t and hence it may be used in an equation which then shows a linear
relationship between FI value and postreinforcement pause.   However,
though the finding of a linearly increasing postreinforcement pause
is frequently cited (e.g. Dukich and Lee, 1973; Lowe, Davey and
Harzem, 1973; Nevin 1973; Sherman 1953; Shull 1971a; 1979; Shull
and Guilkey 1976; Starr and Staddon, 1974) it is in fact based on
very dubious evidence.   The studies that have reported this finding
are as follows : Sherman (1959) employed a between-groups design with
only two rats in each group; Shull (1971a) used two pigeons in a
within-subject design, one bird being trained on two and the other
on three FI values ; Dukich and Lee (1973), with rats as subjects,
used three FI values, these being introduced in ascending order for
each animal.   The study perhaps most often cited as evidence for a
linear relationship between pause and FI value (see for example
Mackintosh, 1974; Shull 1971; Shull and Guilkey, 1976; Staddon,
1972; 1975) is that of Schneider (1969) who, believing that the
first response after reinforcement occurred in a seemingly random
fashion, did not in fact present any postreinforcement pause data.
Several authors appear to have confused the 'break-point' measure,

which Schneider found to be a linear function of FI value with the postreinforcement pause duration.

As was pointed out before, since the FI schedule produces a pattern of responding in which both the minimum reinforced duration and the mean reinforced duration are very close together, it would be of great theoretical interest to find the correct relationship between the postreinforcement pause, which reflects temporal discrimination (cf Ferster and Skinner 1957; Staddon 1972a; 1974) and the fixed-interval value. A recent series of experiments by Lowe, Harzem and Spencer (1979) have attempted to do this. In their first experiment rats were trained on the following FI values, 15, 30, 60, 120, 240 and 480 seconds, in a random order, each of the four animals was trained on each of the FI values. They found that the relationship between the postreinforcement pause and the FI value was not linear, as had been reported in previous studies, but a power function, of the form.

$$T = kt^n \qquad (12)$$

Where T represented the mean postreinforcement pause t was the FI value and k and n were experimental constants. The constant k varied between 2.2 and 1.3 and the exponent n varied between 0.73 and 0.46.

In a second experiment pigeons were used as subjects, being trained on the following FI values 15, 60, 120, 240 and 480 seconds, in a random order. It was again found that the data was best fitted by a power function, the values of the constant k ranging between 0.50 and 2.2 and the exponent n ranging between 0.55 and 0.76.

In the light of this study by Lowe et al (1979), it would seem that Gibbon's (1977) scalar timing hypothesis is in some doubt, as it requires that the postreinforcement pause on an FI schedule should be a linear function of the FI value. Another argument that should be considered concerning Gibbon's (1977) assertion that what the animal is estimating is the mean reinforced duration and not the minimum reinforced duration, is that this analysis of the situation ignores any environmental feedback the animal may be getting from the unreinforced responses.

From the studies reviewed in this chapter, it would appear that an animal's ability to discriminate time is similar to its ability to discriminate physical stimuli such as tone and colour. An animal's sensitivity to variations in duration of a stimulus seems to be best described by Weber's law over quite a wide range. Similarly, the variations in behaviour with that of temporal properties of the environment, as with other physical stimuli, is well described by a power function (cf Stevens 1957).

CHAPTER 4

EXPERIMENTAL METHODS

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

Subjects

The subjects were male hooded rats, purchased from
Animal Suppliers (London) Limited.   All the animals were
housed individually with ad libitum access to water.   A 12 hour
day/night cycle was in effect at all time with the day beginning
at 7.00 a.m. and ending at 7.00 p.m.   The ambient temperature
of the animals 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 its mean weight over the final 5 days of 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 number being specified for each experiment. All experiments were controlled by, and 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 ± 2dB.

Reinforcement.

The reinforcement used in each experiment was a single 45mg Noyes solid food pellet.

General Procedure.

The rats were trained to press the lever by the method of successive approximations (Ferster and Skinner 1957). The criteria for stability on any condition were as follows ; visual inspection of the cumulative records, variation of the mean postreinforcement pause over three consecutive sessions of less than 10% and a minimum training period of 18 sessions. Each session normally lasted until 60 reinforcements had been presented. During training, longer sessions were sometimes used. Data was taken from the last three sessions on each condition.

The experimental designs used in the experiments were 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. emphasis on individual subjects being used as their own controls. In the experiments to be reported, 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).

CHAPTER 5

SOME DETERMINANTS OF PERFORMANCE ON EVENLY PROBABLE TWO-VALUED MIXED FIXED-INTERVAL SCHEDULES.

Very little work has been conducted on what is probably the least complex irregular, temporally defined schedule, the mixed FI. Ferster and Skinner (1957) investigated the performance of pigeons on several mixed FI schedules ; they found, for instance, that on mixed FI 30-sec — FI 300-sec, that the pattern of responding was somewhat irregular, with occasional breaks from responding in the middle of the long interval. A similar pattern of responding was also reported to occur, on mixed FI 60-sec — FI 300-sec, even after the birds had had 400 hours exposure to the schedule. Although they did not present any data for the postreinforcement pause on these schedules, it can be seen, from the cumulative records that were presented, that there was a slight pause following reinforcement.

Catania and Reynolds (1968) also studied performance
on the mixed FI schedule. They kept the long interval, of a
two-valued mixed FI, constant at 240-sec, pairing this with
several different shorter values ranging from 30-sec to 210-sec,
the probability of the short interval either being 0.5 or 0.05.

Using a mixed FI 30-sec — FI 240-sec schedule, with
probability of the short interval occuring at 0.05, they found
a slight decline in the local rate of responding after the first
opportunity for reinforcement, i.e. at 30-sec, followed by an
increase in rate before the terminal reinforcement at the end
of the 240-sec interval. However, when the short interval was
90, 150 or 210-sec, with a probability of 0.05 there was found
to be no such decline in rate between the two opportunities for
reinforcement. A consistent finding of the schedules in which
the probability of reinforcement at the end of the short interval
was 0.05, was that the local rate of responding at the end of the
short interval was greater, the longer the short interval.
The 0.05 probability of reinforcement seemed to maintain a
lower local rate of responding than did the 1.00 probability of
reinforcement, at the end of the long interval.

In schedules where the probability of reinforcement at
the end of the short interval was 0.50, it was generally found
that the local rate of responding at the end of the short interval

was the same as it was at the end of the long interval. The
exception to this was one pigeon that, for each of the schedules
on which it was trained, produced a local rate of responding which
reached a maximum in the middle of the long interval and thereafter
declined. As with the probability of 0.05, it was found that one
of the birds produced an inverted U-shaped function of local rates
of responding at the end of the short interval, the local rate
again increasing before the terminal reinforcement at the end of
the long interval, on the mixed FI 30-sec — FI 240-sec schedule.

As with the study by Ferster and Skinner (1957),
Catania and Reynolds do not present any data for postreinforce-
ment pause. They do, however, present some cumulative records for
one bird, inspection of which reveals a slight postreinforcement
pause on some intervals.

A further experiment by Catania and Reynolds (1968)
looked at the role of the long interval in two-valued mixed FI
schedules. They replaced the reinforcement at the end of the
long interval with a 4-sec time-out, which they took to have no
reinforcing properties. It was reported that the typical pattern
of responding, on mixed FI, was maintained in this schedule when
the probability of reinforcement at the end of the short interval
was 0.50, however, when this probability was reduced to 0.05 the

animals only responded at a very low rate or not at all. They
suggested that this lack of responding in the 0.05 condition was
due to the very low overall rate of reinforcement delivery (less
than one reinforcement per hour) which was insufficient to
maintain responding at all. From the other condition, it may be
concluded that the terminal reinforcement was having a
discriminative influence upon behaviour as well as maintaining it,
since a neutral stimulus presented in lieu of reinforcement had
a similar effect upon the local rate of responding. This effect
being analogous to the omission effect, discussed in Chapter 2
(cf Staddon 1972a).

Another study that was concerned with the pattern of
responding on mixed FI schedules, that does report postreinforce-
ment pause data, is that of Dukich and Lee (1973). They trained
rats on several evenly probable mixed FI schedules. There were
three sets of schedules, each set having a different long interval,
30-sec, 60-sec and 120-sec. With each of these long intervals
several short intervals were paired, ranging from 24-sec to
28.5-sec with the 30-sec long interval, 51-sec to 57-sec with the
60-sec long interval and 60-sec to 108-sec with the 120-sec long
interval.

They found a certain degree of ambiguity as to the
effect of the short interval upon the duration of the postreinforce-
ment pause.   None of the rats showed any systematic relationship
between the length of the postreinforcement pause and the degree
to which the short interval was reduced.   For example, all three
rats trained on the schedules with the long interval of 60-sec,
produced a longer postreinforcement pause when the short interval
was 54-sec than when it was 57-sec, but when the short interval
was reduced to 51-sec the pause decreased to less than it was
when the short interval was 57-sec.   Similar ambiguity was
found for the animals trained on the schedules in which the long
interval was 30-sec.   In the schedules in which the long interval
was 120-sec the relationship between postreinforcement pause and
the short interval was slightly clearer.   In this set of mixed
FIs both the relative and the absolute difference in values
between the short intervals was considerably greater than in
either of the other two sets of schedules.   With the exception
of just one rat that produced a longer pause on mixed FI 108-sec --
FI 120-sec than it did on FI 60-sec, it was found on this schedule
that there was a systematic decrease in the duration of the
postreinforcement pause with decreases in the duration of the
short interval.

It would appear from the above results that there is
some relationship between the duration of the short interval in a

mixed FI schedule and the duration of the postreinforcement pause, although the exact relationship is unclear and would seem to require further systematic studies. One possible relationship could be that the postreinforcement pause is entirely determined by the duration of the short interval. This relationship would follow from the relative proximity principle (Staddon 1972a) and the finding by Catania and Reynolds (1968) that a probability of reinforcement of 0.50 will maintain the same local rate of responding as will a probability of 1.00. Thus, since a probability of reinforcement of less than one will have the same effect on earlier responding as a probability of 1.00, it would be expected that a time marker, such as the delivery of a reinforcer, that predicted a 0.50 probability of reinforcement in t-seconds would develop the same inhibitory after-effects as a time marker that predicted reinforcement in t-seconds with a probability of 1.0. Thus, it would be expected that the two time marks would be followed by the same postreinforcement pause. Since on an evenly probable mixed FI the delivery of reinforcement does predict reinforcement at the end of the short interval, with a probability of 0.5, it would be expected that the pause would be equivalent to that which would occur on an FI schedule of the same value.

The first experiment was designed to systematically investigate the effect upon the duration of the postreinforcement pause and subsequent pattern of responding, of the manipulation of the parameters of an evenly probable two-value mixed FI schedule.

Experiment 1.

Method.

Subjects.

Four male hooded rats, approximately 12 weeks' old at the start of the experiment were individually housed and maintained at 80% of their free-feeding weight throughout the duration of the experiment. Water was freely available in the home cages.

Apparatus.

Four Lehigh Valley Model 142-25 chambers, with the right lever only. The house light remained off throughout the duration of the experiment. The experiment was controlled by, and data were recorded and analysed on, a NOVA 1200 computer.

Procedure.

Lever-pressing responses were shaped in the first session, the animals were then allowed to obtain 60 contingent reinforcements on a CRF schedule. After this preliminary

Table 1.   Experiment 1.

The conditions and the number of
sessions of training on each condition,
presented in the order in which
the animals were trained on them ;
for each animal.   The fourth column
shows the mean postreinforcement
pause (PRP) on each condition, and
the fifth column the standard
deviation (SD) of the pauses.

Table 1.

Animal	Schedule	Number of Sessions	Postreinforcement Pause	
			Mean	SD
R1	FI60 sec	73	41.36 sec	13.03 sec
	Mixed FI20-FI 60 sec	20	23.90 sec	8.29 sec
	Mixed FI60-FI100 sec	18	56.74 sec	17.14 sec
	Mixed FI40-FI 60 sec	20	46.20 sec	13.91 sec
	Mixed FI60-FI 80 sec	18	57.46 sec	16.33 sec
	Mixed FI60-FI100 sec	24	50.85 sec	12.92 sec
	FI60 sec	16	53.12 sec	12.89 sec
R2	FI60 sec	70	38.97 sec	13.96 sec
	Mixed FI20-FI 60 sec	17	15.47 sec	6.89 sec
	Mixed FI60-FI100 sec	18	40.41 sec	16.11 sec
	Mixed FI40-FI 60 sec	16	38.37 sec	12.69 sec
	Mixed FI60-FI 80 sec	16	44.02 sec	19.71 sec
	Mixed FI60-FI100 sec	24	50.93 sec	13.78 sec
	FI60 sec	17	51.88 sec	13.52 sec
R3	FI60 sec	74	41.21 sec	14.98 sec
	Mixed FI20-FI 60 sec	18	16.68 sec	6.23 sec
	Mixed FI60-FI100 sec	19	38.75 sec	18.44 sec
	Mixed FI40-FI 60 sec	18	33.41 sec	8.45 sec
	Mixed FI60-FI 80 sec	19	44.78 sec	15.02 sec
	Mixed FI60-FI100 sec	24	44.32 sec	16.24 sec
	FI60 sec	16	42.16 sec	14.88 sec
R4	FI60 sec	73	35.26 sec	13.69 sec
	Mixed FI20-FI 60 sec	18	11.21 sec	5.66 sec
	Mixed FI60-FI100 sec	18	34.64 sec	15.49 sec
	Mixed FI40-FI 60 sec	19	23.21 sec	12.42 sec
	Mixed FI60-FI 80 sec	19	32.12 sec	12.92 sec
	Mixed FI60-FI100 sec	24	31.13 sec	13.35 sec
	FI60 sec	16	32.39 sec	13.37 sec

training the animals were placed on an FI 60-sec schedule until they were considered to be producing a stable pattern of responding. The animals were then trained on several mixed FI schedules in which one interval was always 60-sec, occurring randomly with a probability of 0.5. The second intervals were as follows : 20-sec, 40-sec, 80-sec and 100-sec. The order in which the animals were trained on these schedules and the number of sessions of training given on each schedule is given in Table 1. Two redetermination conditions were also conducted. Training on all conditions was conducted until the animal's behaviour was considered to be stable, data being taken from the last three sessions of training in each condition.

Results and Discussion.

Figure 1 shows the mean postreinforcement pause of the last three sessions of training for each schedule, plotted against the value of the interval that was randomly presented with the 60-sec interval. It can be quite clearly seen that as the duration of the short interval increased from 20-sec to 60-sec the duration of the postreinforcement pause also increased. When, however, the short interval was held constant at 60-sec and the long interval increased, there was no apparent systematic increase in the duration of the postreinforcement pause.

Figure 1.   Experiment 1 :

The postreinforcement pause on the mixed

FI schedules for animals R1, R2, R3 and

R4, as a function of the 'second interval'

(i.e. the value of the interval paired

with the 60-sec interval).   The

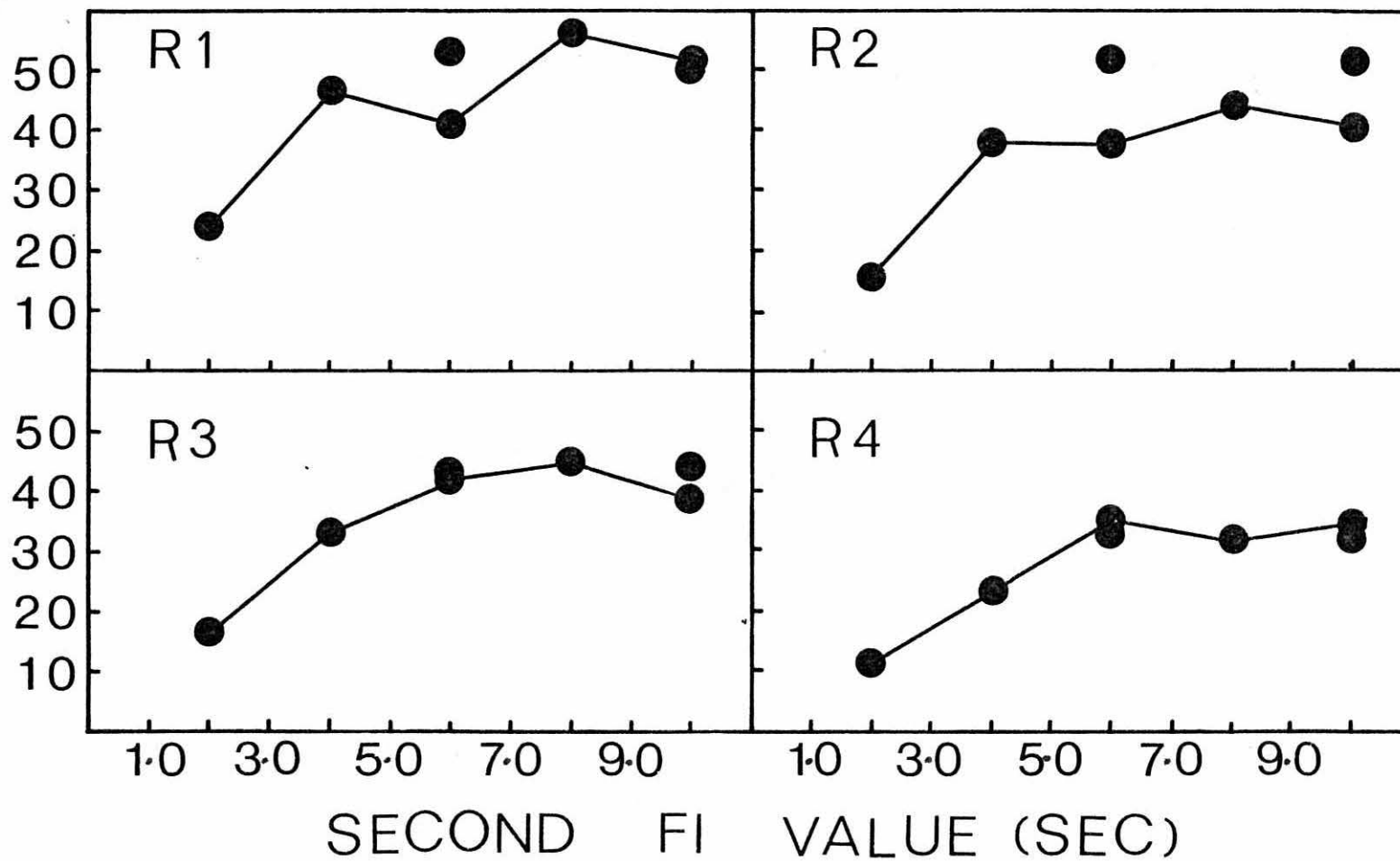unconnected points are redetermination

conditions.

Figure 2.   Experiment 1 :

The postreinforcement pause, relative to

the duration of the short interval in the

mixed FI schedules, plotted against the

value of the ratio between the two

intervals making up the schedule, for

animals R1, R2, R3 and R4.   The
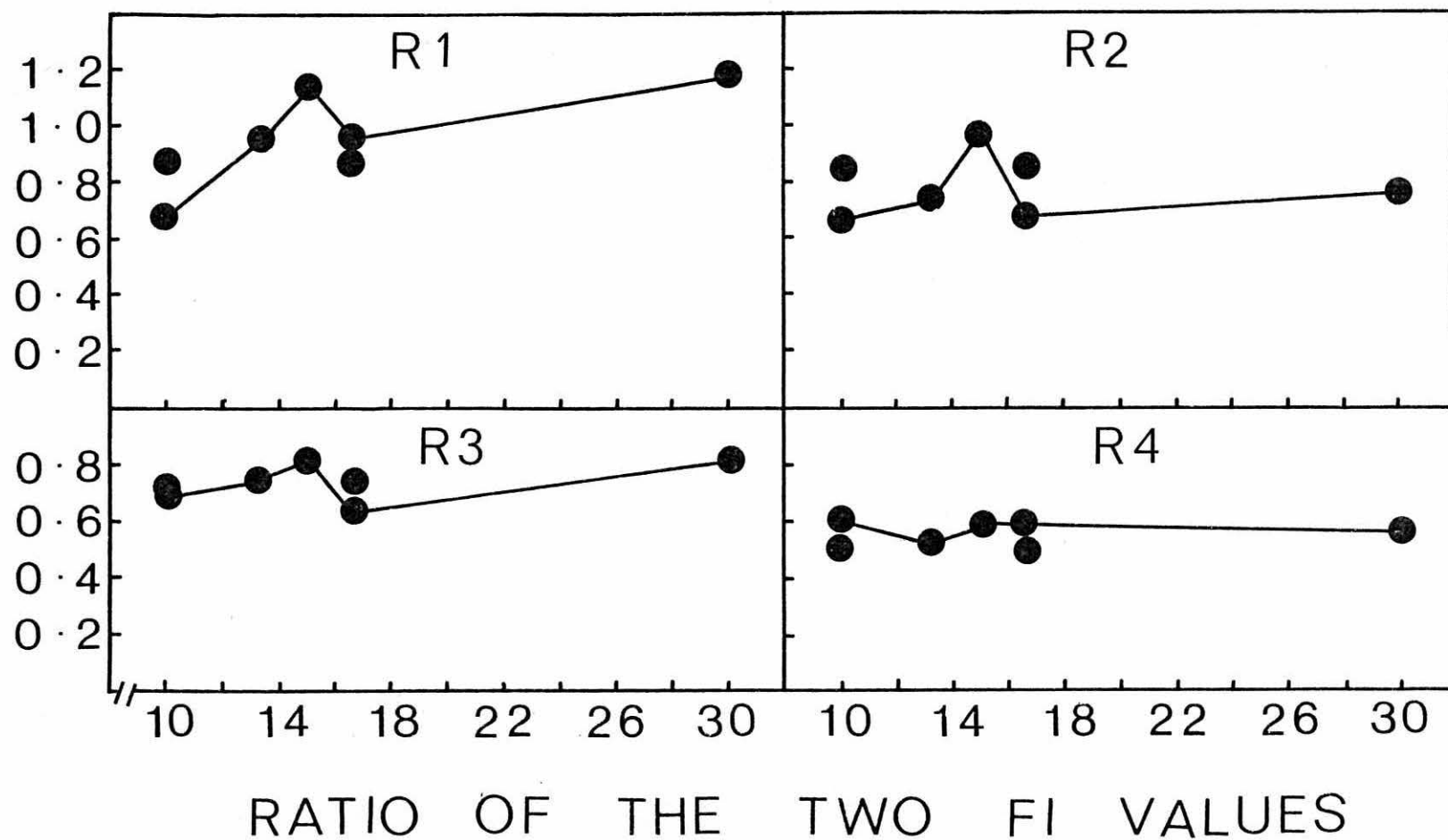
unconnected points are redetermination

conditions.

Figure 2 represents the postreinforcement pause relative
to the short interval (that is the mean postreinforcement pause
on a particular schedule divided by the duration of the short
interval), plotted against the ratio between the values of the
two intervals making up the mixed FI schedule. It would be expected
that, if the postreinforcement pause was entirely determined by the
duration of the short interval, the graphs would be almost
horizontally straight lines. This would follow from the finding
of Lowe, Harzem and Spencer (1979) that over this range of
intervals, that duration of the postreinforcement pause on an FI
schedule would be virtually a constant fraction of the FI value.
Any major systematic deviation from the horizontal could be taken
as reflecting the influence of the long interval in the
determination of the postreinforcement pause.

Figure 2 also shows that the main determining factor
of the postreinforcement pause was the duration of the short
interval. The relative pause did vary to some extent with
different ratios of intervals making up the mixed FI. All the
animals, with the possible exception of R4, reach a peak in
relative postreinforcement pause duration when the ratio between
the two intervals was 1.5 (i.e. on mixed FI 40 — FI 60) ; this
was then followed by a decline in relative pause, when the ratio
was increased to 1.67. One possible explanation for this could
be that the peak occurs with a mixed FI in which the small
interval was 40-sec, whereas the two adjacent points were produced

Figure 3.   Experiment 1 :

The local rates of responding across

the long interval of all the conditions,
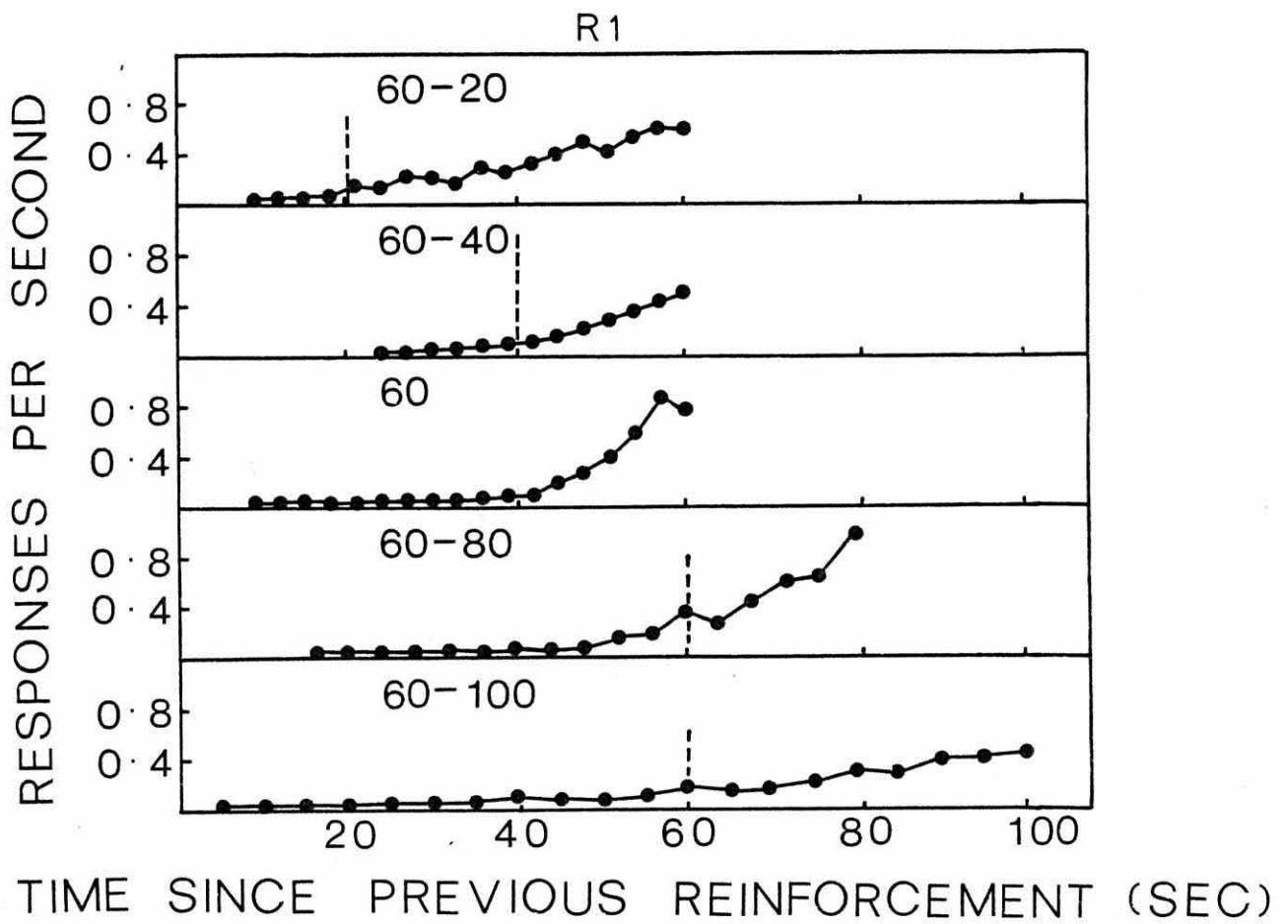
for animal R1.

Figure 4.   Experiment 1.

The local rates of responding across

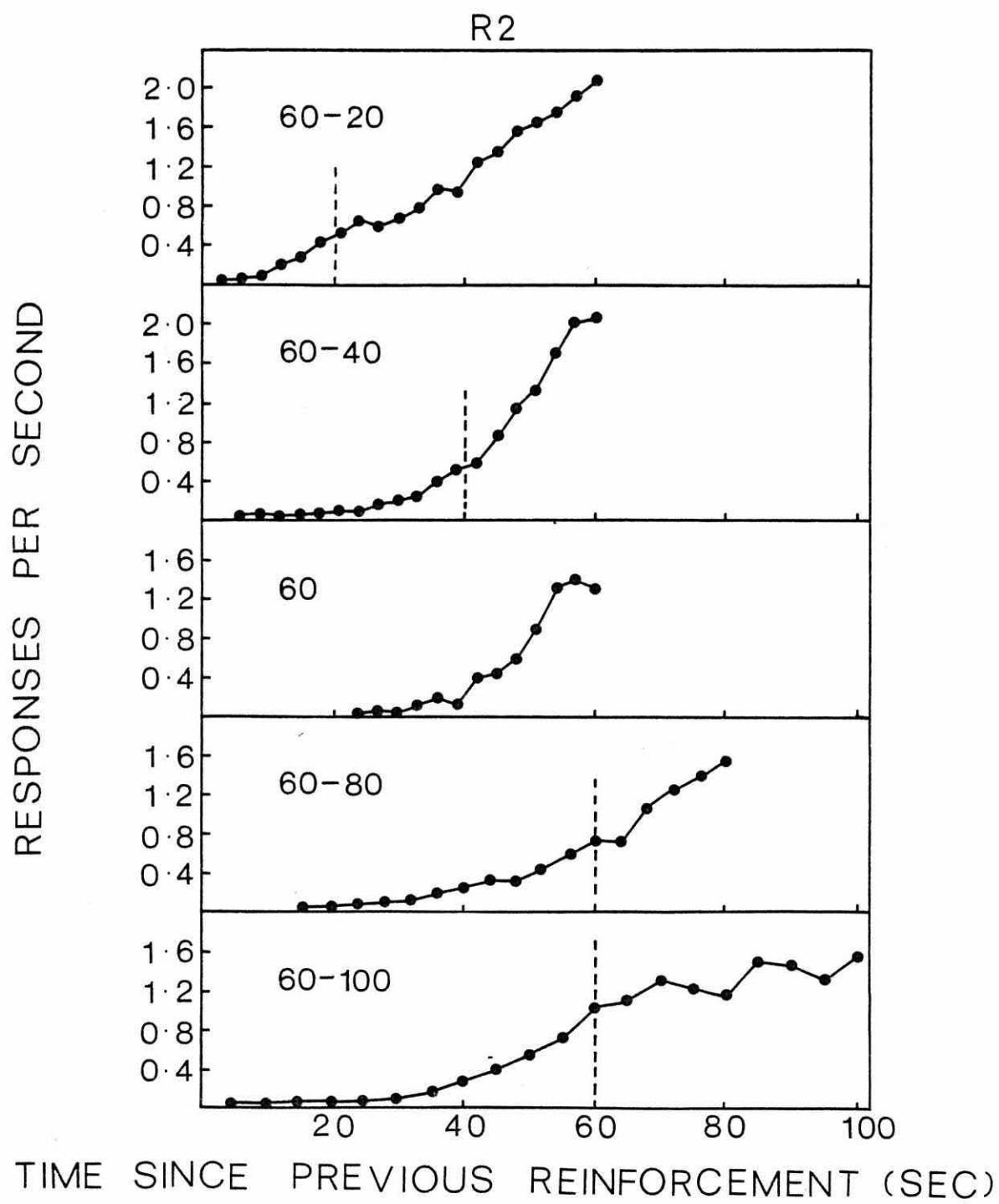the long interval of all the conditions,

for animal R2.

Figure 5.   Experiment 1 :

The local rates of responding across the

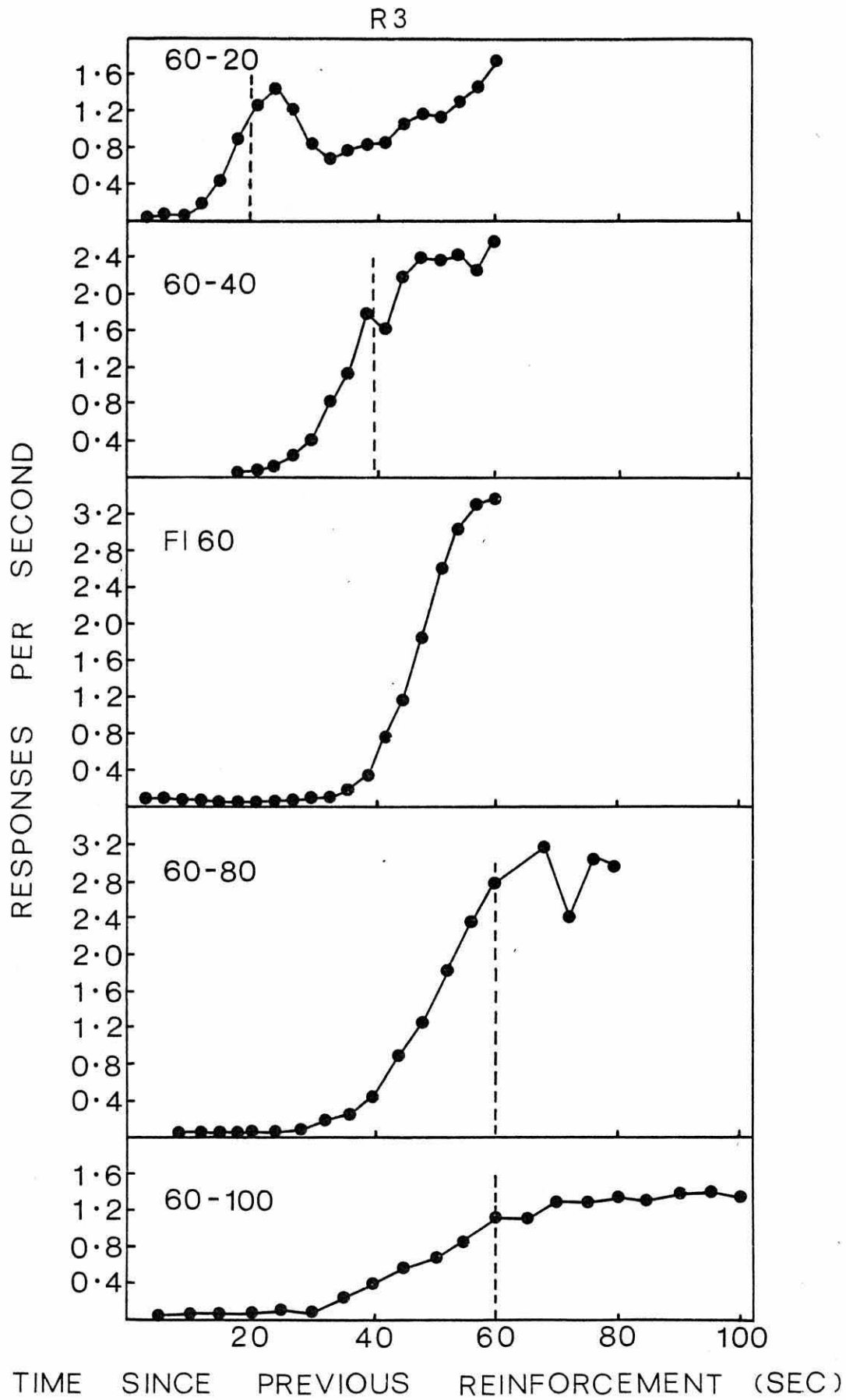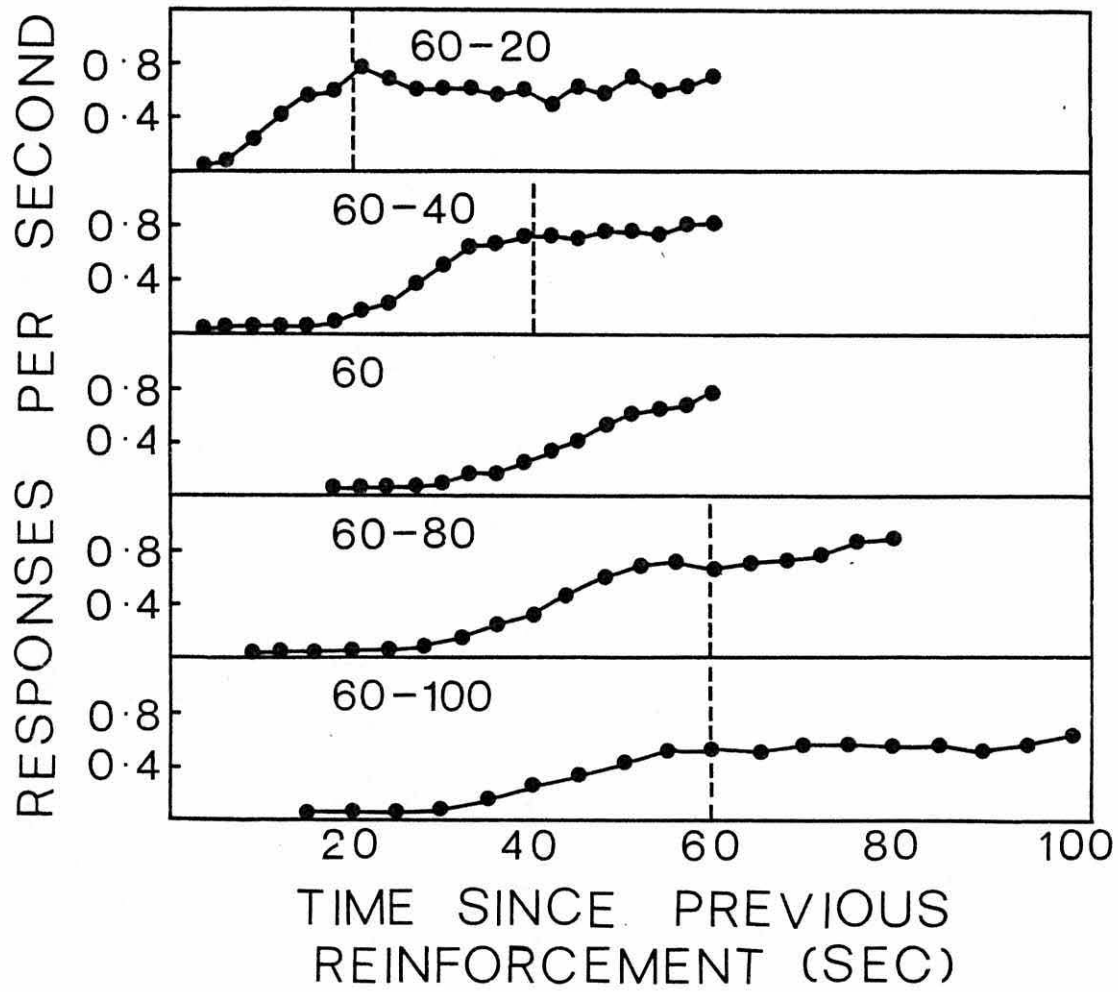long interval of all the conditions, for

animal R3.

Figure 6.   Experiment 1:

The local rates of responding across the

long interval of all the conditions, for

animal R4.

by mixed FI schedules in which the small interval was 60-sec. Thus, according to Lowe, Harzem and Spencer's (1979) power function, it would be expected that there would be a slightly longer relative pause for a small interval of 40-sec than there would be for a small interval of 60-sec, even if the pause on a mixed FI schedule was entirely determined by the small interval. However, when this is looked at more closely it does not seem to be the full explanation as the actual difference in the relative postreinforcement pause that would be predicted by Lowe et al's power function, between FI 60-secs and FI 40-secs, would be only 0.06. As can be seen from Figure 2, the difference in the relative pause around this peak is much greater than this for three out of the four animals.

Animal R4 seems, on the whole, to produce a constant relative postreinforcement pause, showing that with this animal that the short interval does, virtually entirely, determine the postreinforcement pause.

Figure 3 shows the local rates of responding for Animal R1 on all the conditions. It can be seen that there was a very low rate of responding just after the delivery of reinforcement, followed by a gradual acceleration in the rate of responding until the terminal reinforcement. The broken vertical line marks the point at which reinforcement could be delivered at the end of the short interval. It can be seen that at this point there is consistently a lower local rate of responding than there is at

the point at which reinforcement is delivered, at the end of the
long interval.   This finding conflicts with the finding by
Catania and Reynolds (1968) that a probability of reinforcement
of 0.50 would maintain the same local rate of responding as would
a probability of 1.00.

The performance of Animal R2 is shown in Figure 4.
This subject's pattern of behaviour was very similar to that of
Animal R1, though its overall rate of responding did seem to be
higher.   Figure 5 shows the performance of Animal R3.   This
animal had the general characteristics of Animals R1 and R2, in
that it produced a low local rate of responding just after the
delivery of reinforcement, but seems to produce a different pattern
of local rates of responding on the different schedules on which
it was trained.   With the mixed FI 20 — FI 60-sec schedule the local
rate of responding continues to increase after the 20-sec point
from the previous reinforcement, reaching a peak at about 24-sec,
followed by a decline in rate in the middle of the 60-sec interval,
and then an acceleration in rate before the terminal reinforcement
at the end of the 60-sec interval.   A similar finding was reported
by Catania and Reynolds (1968) for one of their pigeons on mixed
FI 30 — FI 240-sec.

The performance of animal R4, in Figure 6, can be seen to
be consistent between conditions, in that it reached it's maximum
local rate of responding at the end of the short interval.   This
would seem to be consistent with the finding that the pause produced

by this animal is entirely determined by the duration of the short interval (Figures 1 and 2), since it would seem that the local rate of responding is fully determined by the short interval.

The general conclusions that can be drawn from the results of this experiment is that the postreinforcement pause seems to be mainly determined by the duration of the short interval. There is some evidence that the long interval may exert some influence upon the duration of the pause when the ratio between the two intervals making up the mixed FI is 1.5. Though from these results it is not possible to tell whether the increased relative pause, that occurs when the ratio between the two intervals was 1.5, was due to the relative or absolute difference between the two intervals. A further experiment was performed to clarify these findings over a different range of intervals. It was hoped that it would spread further light onto the effect of mixed FI schedules on local rate of responding. This was done by repeating Experiment I using double the values of the intervals making up the mixed FI schedules.

Experiment II.

Method.

Subjects.

Four male hooded rats, approximately 12 weeks' old at the start of the experiment, were individually housed and maintained at 80% of their free-feeding body weight throughout the experiment. Water was freely available in the home cages.

Apparatus.

The apparatus was the same as in the previous experiment.

Procedure.

Lever-pressing responses were shaped in the first session, the animals were then allowed to obtain 60 contingent reinforcements on a CRF schedule. After this preliminary training the animals were placed on an FI 120-sec schedule until they were considered to be stable. They were then trained on several mixed FI schedules in which one interval was always 120-sec, which occurred randomly with a probability of 0.50, the second intervals being as follows : 40-sec, 80-sec, 160-sec and 200-sec. The order in which the animals were trained on these schedules and the number of sessions of training given on each schedule are given in Table 2. Two redetermination conditions

Table 2.   Experiment 2 :

The conditions and the number of

sessions of training on each condition

presented in the order in which

the animals were trained on them ;

for each animal.   The fourth column

shows the mean postreinforcement

pause (PRP) on each condition, and

the fifth column the standard

deviation (SD) of the pauses.

Table 2.

Animal	Schedule	Number of Sessions	Postreinforcement Pause	
			Mean	SD
R5	FI120 sec	75	93.06 sec	30.27 sec
	Mixed FI120-FI200 sec	20	79.40 sec	27.76 sec
	Mixed FI 40-FI120 sec	24	36.89 sec	17.09 sec
	Mixed FI120-FI160 sec	35	96.03 sec	28.12 sec
	Mixed FI 80-FI120 sec	17	69.95 sec	22.29 sec
	Mixed FI 40-FI120 sec	41	41.75 sec	17.29 sec
	FI120 sec	23	92.21 sec	30.87 sec
R6	FI120 sec	73	79.52 sec	27.81 sec
	Mixed FI120-FI200 sec	19	82.15 sec	27.38 sec
	Mixed FI 40-FI120 sec	24	21.82 sec	11.24 sec
	Mixed FI120-FI160 sec	33	78.74 sec	24.22 sec
	Mixed FI 80-FI120 sec	18	57.38 sec	19.70 sec
	Mixed FI 40-FI120 sec	42	27.52 sec	10.95 sec
	FI120 sec	25	84.28 sec	26.39 sec
R7	FI120 sec	73	69.24 sec	34.86 sec
	Mixed FI120-FI200 sec	18	69.09 sec	27.04 sec
	Mixed FI 40-FI120 sec	23	28.68 sec	13.14 sec
	Mixed FI 20-FI160 sec	36	82.62 sec	26.33 sec
	Mixed FI 80-FI120 sec	18	62.20 sec	17.79 sec
	Mixed FI 40-FI120 sec	42	31.94 sec	10.79 sec
	FI120 sec	26	79.17 sec	30.81 sec
R8	FI120 sec	72	66.74 sec	27.30 sec
	Mixed FI120-FI200 sec	18	66.78 sec	23.80 sec
	Mixed FI 40-FI120 sec	23	20.33 sec	7.95 sec
	Mixed FI 20-FI160 sec	32	70.73 sec	20.02 sec
	Mixed FI 80-FI120 sec	19	50.95 sec	16.76 sec
	Mixed FI 40-FI120 sec	42	30.21 sec	8.31 sec
	FI120 sec	27	65.43 sec	26.19 sec

were also conducted.   Training on all conditions was continued
until the animals' behaviour were considered to be stable.   Data
was taken from the last three sessions of training in each condition.

Results and Discussion.

The postreinforcement pause on each condition is shown
in Figure 7 for each of the animals.   The pause being plotted
as a function of value of the second interval (i.e. the interval
that was paired with the 120-sec interval).   It can be seen
quite clearly that, as with Experiment I, the postreinforcement
pause increased as the short interval increases from 40-sec to
120-sec.   But when the short interval was held constant at
120-sec and the long interval is increased there does not appear
to be any systematic change in the duration of the pause.   This
again suggests that the long interval in an evenly probable, two
valued, mixed FI schedule, has very little influence upon the
duration of the postreinforcement pause.

As in the last experiment there were several different
short intervals used in the different mixed FI schedules (40-sec,
80-sec, and 120-sec).   If the longer interval had no effect in
determining the postreinforcement pause then, again, it would be
expected that the postreinforcement pause relative to the short
interval would vary very little over the range of short intervals
used in this experiment (Lowe, Harzem and Spencer 1979).
Figure 8 shows the functions of relative postreinforcement pause
to the short interval against the ratio of the two intervals
making up the mixed FI.   Here, again, it can be seen that the

Figure 7.　　Experiment 2 :

The postreinforcement pause on the
mixed FI schedules for animals R5,
R6, R7 and R8, as a function of the
'second interval' (i.e. the value of
the interval paired with the 120-sec
interval).　The unconnected points
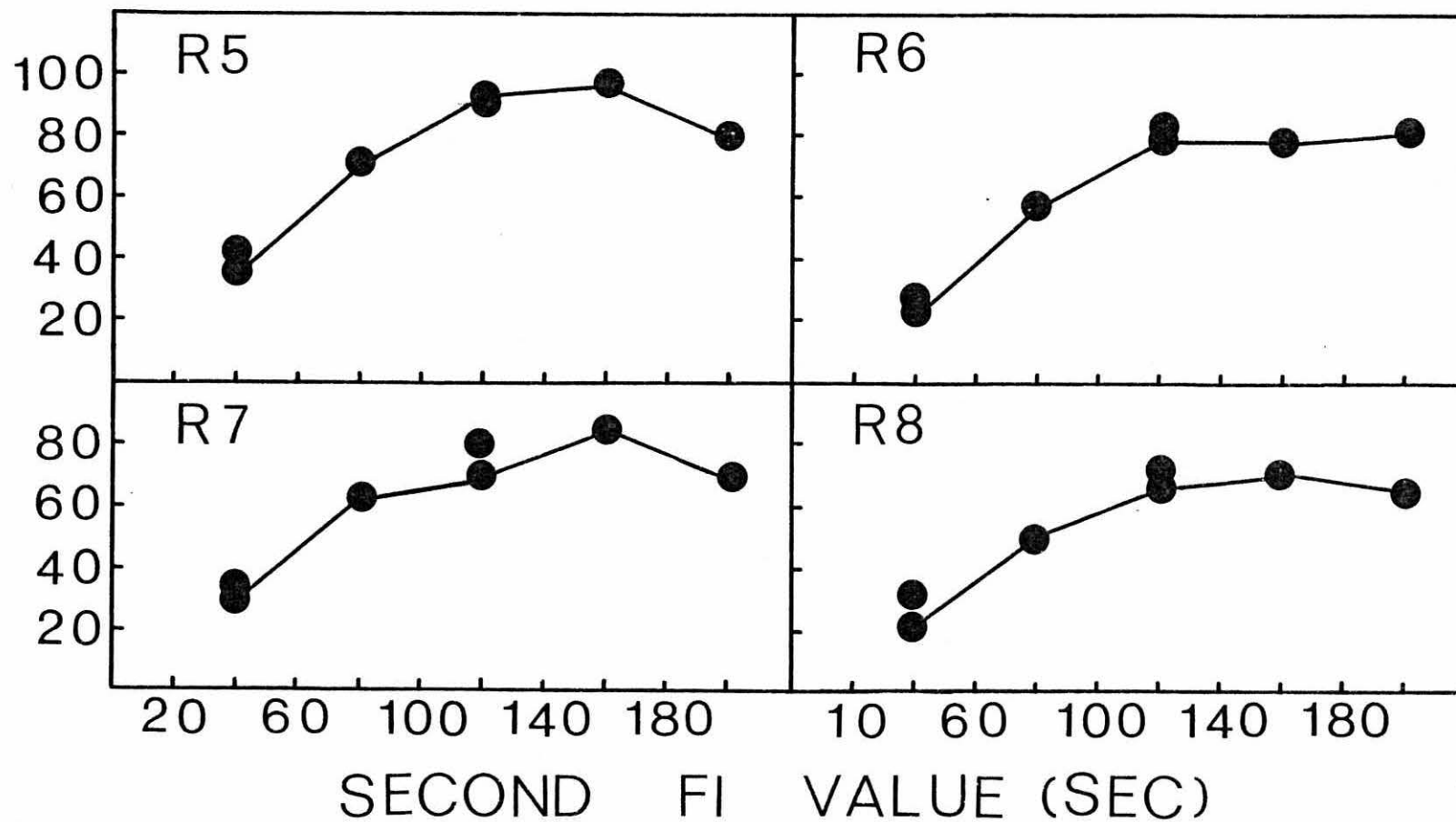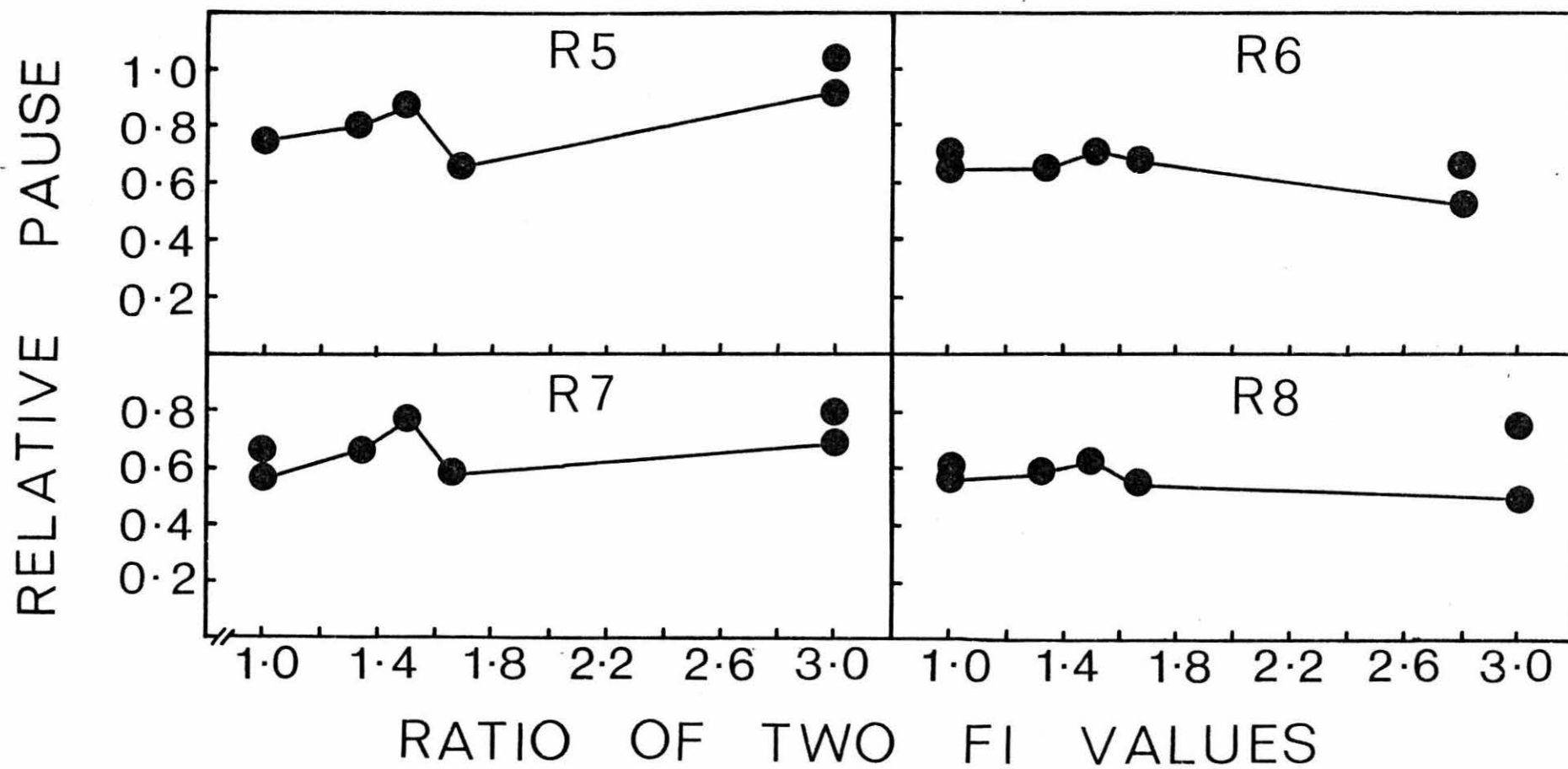are redetermination conditions.

Figure 8.   Experiment 2 :

The postreinforcement pause, relative

to the duration of the short interval

in the mixed FI schedules, plotted

against the value of the ratio between

the two intervals making up the

schedules ; for animals R5, R6, R7 and

R8.   The unconnected points are

redetermination conditions.

long interval seemed to have very little influence in
determining the postreinforcement pause, the functions being
virtually horizontal for each animal.   There is again a
slight peak in the relative postreinforcement pause at the
point at which the ratio between the two intervals is 1.5.
This finding suggests that the phenomenon was due to the
relative rather than the absolute difference between the two
intervals.   There is again the possibility that the peak was
due to the fact that it occurs in a condition in which the
small interval was less than the short interval on the condition
represented by the two adjacent points.   This though again,
would not seem to be the full explanation, since the mean
power function relating postreinforcement pause to FI value would
only predict a difference in relative postreinforcement pause of
0.05, and it can be seen from Figure 8 that the majority of
the differences were greater than this.

Figure 9 shows the local rates of responding on all
the conditions for Animal R5.   It can be seen that this animal's
behaviour was typified by a low local rate of responding just
after reinforcement had been delivered, followed by a gradual
acceleration in rate until the terminal reinforcement at the end
of the long interval.   The performance of Animal R6, shown in
Figure 10, can be seen to be essentially the same.

Figure 9.   Experiment 2 :

The local rate of responding across

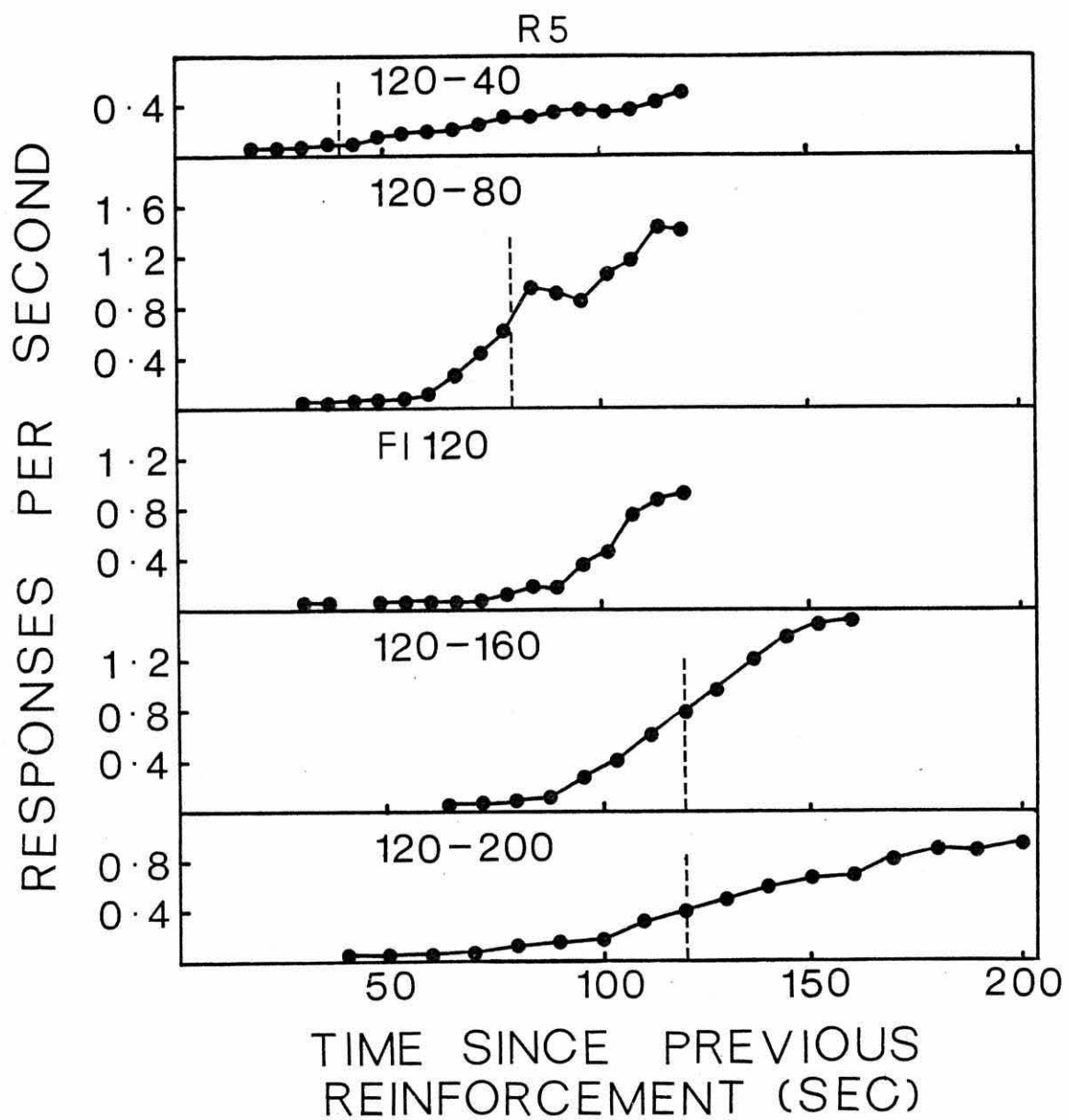the long interval for all conditions,

for animal R5.

Figure 10.   Experiment 2:

The local rate of responding across

the long interval for all conditions,
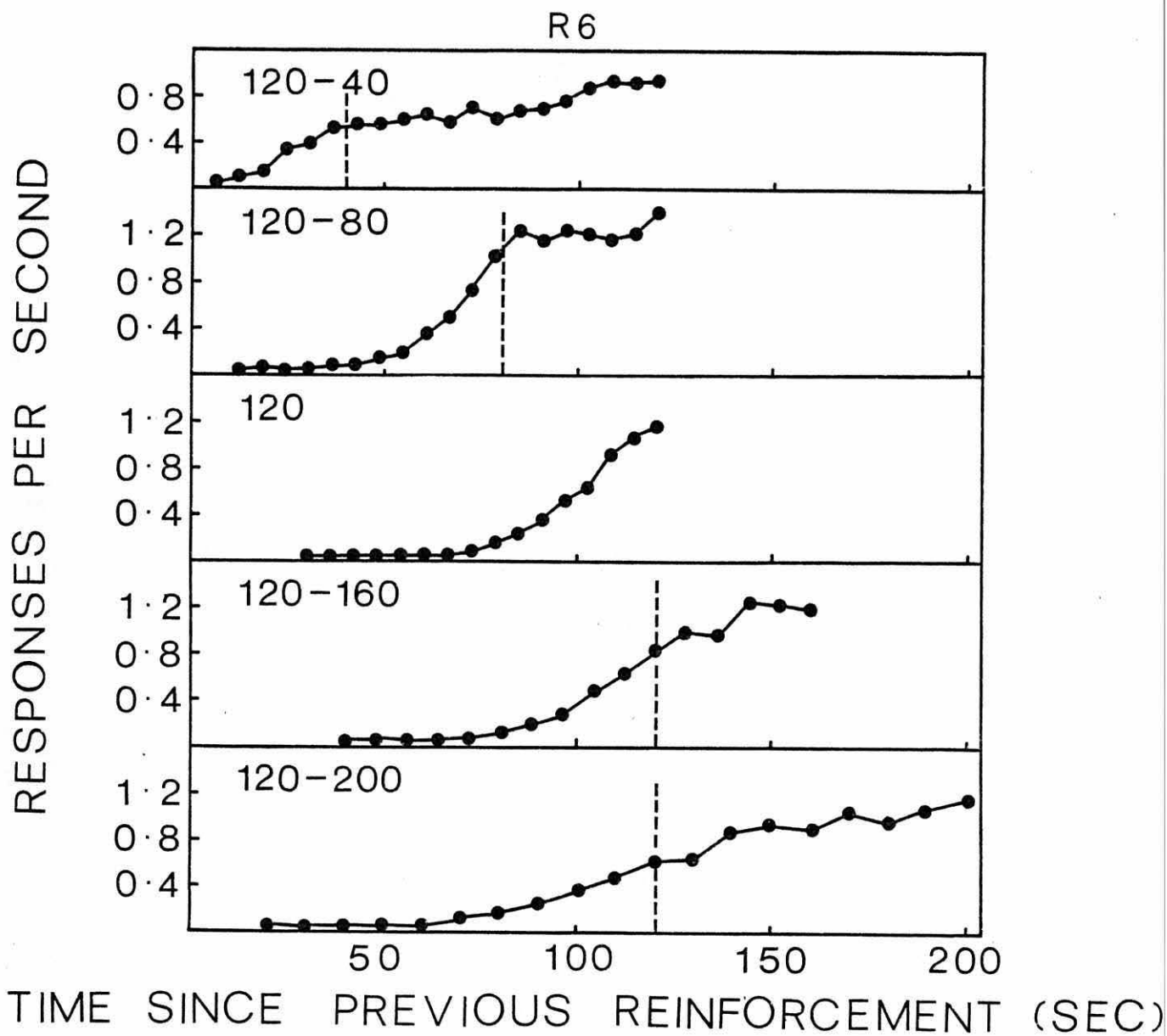
for animal R6.

R6

Figure 11.   Experiment 2 :

The local rate of responding across
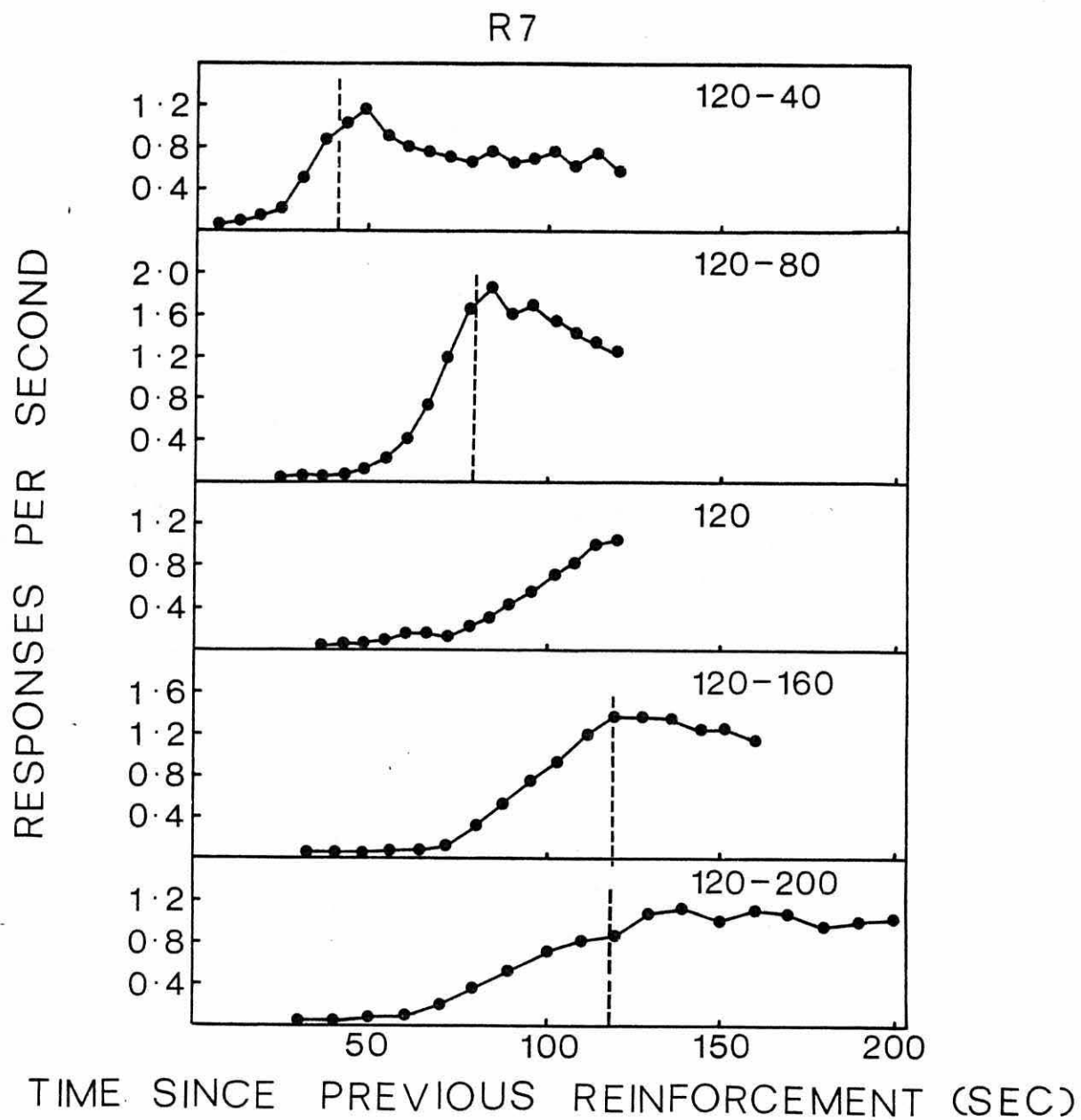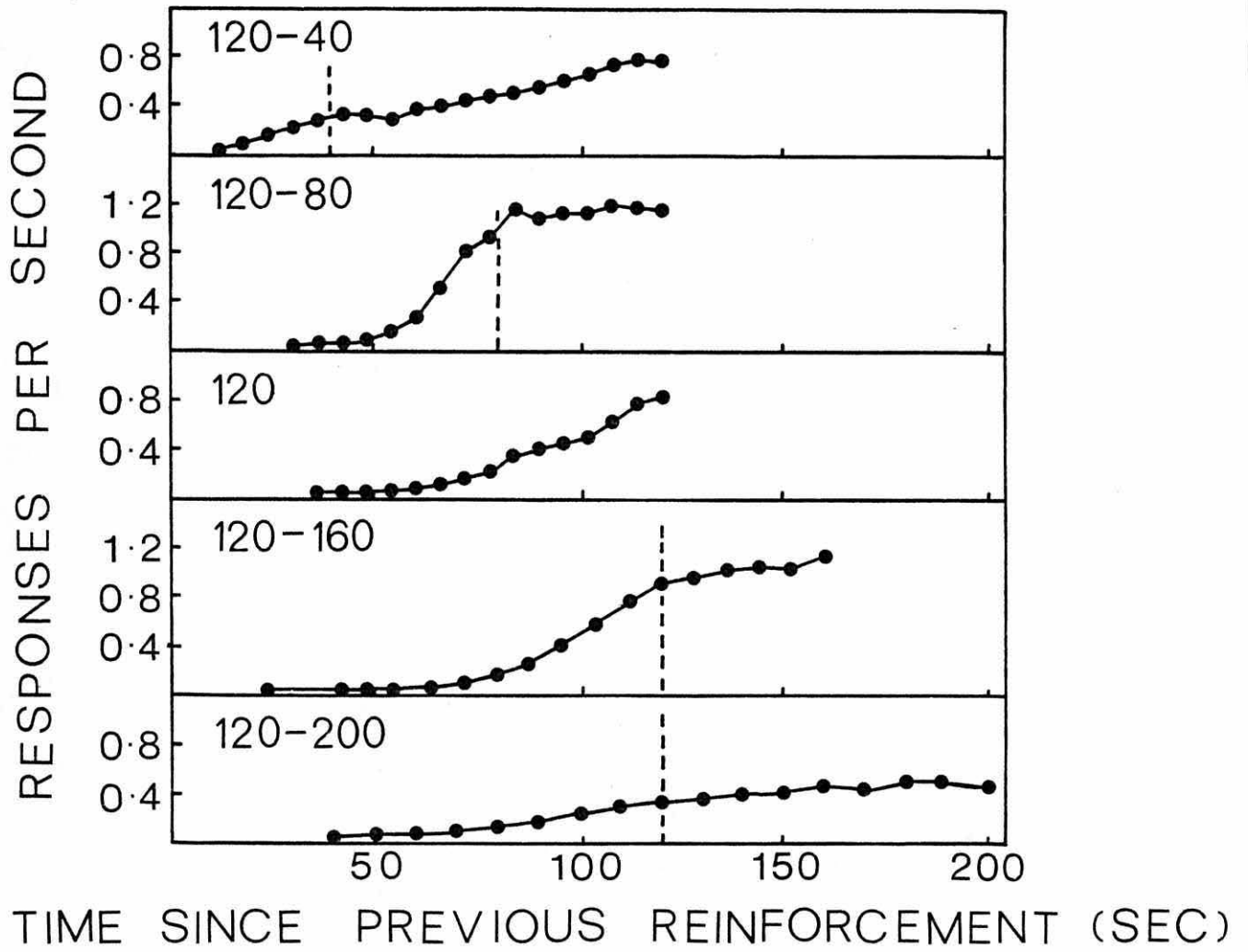
the long interval for all conditions,

for animal R7.

Figure 12.   Experiment 2 :

The local rate of responding across

the long interval for all conditions,

for animal R8.

Animal R7's performance is shown in Figure 11. The performance of this animal was not constant between conditions. On the mixed FI 40 — FI 120-sec and the mixed FI 80 — FI 120-sec condition, this animal showed a peak in its local rate of responding just after the end of the short interval, followed by a decline in local rate of responding until the end of the long interval. Though its pattern of responding on the other conditions was similar to that of Animals R5 and R6. The performance of Animal R8 is shown in Figure 12, and was typical of that produced by the other animals in the experiment.

On the whole the results of this experiment are consistent with the results of Experiment I. Manipulating the relative differences between the two intervals making up a mixed FI has very little effect upon the postreinforcement pause, which seems to be mainly determined by the duration of the short interval. Such variation as there is in the postreinforcement pause relative to the short interval, with variation in the relative differences between the two intervals seems to follow the same pattern in both Experiment I and Experiment II suggesting that this effect is due to the relative rather than the absolute difference between the two intervals.

General Discussion

Taking the results of Experiments I and II together, it may be concluded that the major controlling variable of the postreinforcement pause on an evenly probable mixed FI schedule is the duration of the short interval. This result is consistent with other work done on the determination of the postreinforcement pause on two-valued temporally defined schedules. Harzem, Lowe and Spencer (1978) used an FI schedule, with the added contingency that if the animal paused after reinforcement for a minimum interval, reinforcement would be delivered for the first response after reinforcement, a DRL contingency ; if the pause was less than this minimum interval, then the animal was reinforced for the first response after the FI interval elapsed. They reported that, when the DRL contingency duration and the FI value were manipulated, the length of the postreinforcement pause was appropriate to whichever contingency, either FI or DRL, that would be expected to produce the shortest postreinforcement pause. Similar results were also reported by Logan (1967), using a mixed DRL schedule ; he found that his subjects postreinforcement pause was that which would be expected to correspond to the short DRL value. It would seem that it is the relative proximity to the first opportunity for reinforcement that is the main determinant of the postreinforcement pause in simple irregular temporally defined schedules.

It has been noted that in both Experiments I and II, with some of the subjects, the long interval does seem to have some effect upon the duration of the postreinforcement pause, this effect being particularly pronounced when the ratio between the two intervals was 1.5. One possible explanation for this could lie in the field of temporal psychophysics. Rilling (1967) performed an experiment in which pigeons responded on a mixed FI schedule, with the modification that at the end of the interval the pigeon had to make a choice appropriate to the interval duration it had just completed, in order to be reinforced. He found that when the ratio between the two intervals was 1.5 or less that the birds began to make errors of choice. It could be the case that when an animal is responding on a mixed FI schedule in which the ratio between the two intervals is less than 1.5, that it fails to discriminate that there are two different interval values in operation. The postreinforcement pause then results from a combination of influences from both intervals.

The local rates of responding observed in these experiments are somewhat different to those reported by Catania and Reynolds (1968) using pigeons as subjects. They found that the local rates of responding that occurred at the end of a short interval were the same as the local rates of responding that occurred at the end of a long interval. In these present experiments this was

generally found not to be the case, with the local rate of
responding being greater at the end of the long interval than
it was at the end of the short interval.   There were a few
notable exceptions.   For example, animal R3 on mixed FI 20 —
FI 60-sec, produced an inverted U-shaped gradient of local rate
of responding over a point just after the end of the short
interval.   A similar pattern of responding was also observed
for animals R7 on mixed FI 40 — FI 120-sec, although in this
case the local rate does not recover again at the end of the long
interval following the decline in the local rate of responding
in mid-interval.   A similar pattern of responding was also
reported by Catania and Reynolds (1968), for one of their pigeons
on mixed FI 30 — FI 240-sec.   A notable feature of both the
inverted U-shaped distributions reported here, and by Catania
and Reynolds, is that they only occurred when there was a
relatively large ratio between the two intervals making up the
mixed FI schedule, 3 : 1 in the case of animals R3 and R7, and
8 : 1 in the case of Catania and Reynolds pigeon.   A hypothesis
that may be helpful in explaining this phenomenon has been put
forward by Catania and Reynolds (1968).   They state the following :

> 'The spread of effect of reinforcement at one
> time since reinforcement to local rate of
> responding at other times could be interpreted
> in terms of a gradient of temporal generalization.
> The performance maintained by an FI schedule may

reflect such a gradient, but by its nature
the FI schedule can provide only one side of
such a gradient : up to the time at which
reinforcement is made available but not
beyond that time. (P.369)'

Thus, the reduction in rate following the peak in the
local rate of responding just after the end of the short interval,
may be interpreted as being the right-hand side of a temporal
generalization gradient. This suggestion would seem to merit
further investigation, and it is with this that the next chapter
will be concerned.

CHAPTER 6

SOME DETERMINANTS OF PERFORMANCE
ON EVENLY PROBABLE TWO-VALUED MIXED FIXED-INTERVAL SCHEDULES : 2

If Catania and Reynolds' (1968) idea, that the spread of
effect of reinforcement upon the local rate of responding could be
interpreted in terms of a gradient of temporal generalization, is
correct, it would have great significance, not only for the explan-
ation of the pattern of responding produced in regularly defined
fixed-interval schedules, but also for the irregularly temporally
defined schedules of reinforcement.

Catania and Reynolds go on to suggest that the performance
maintained by an FI schedule may reflect the left-hand side of a
temporal generalization gradient. If this were so, it would imply

that temporal discrimination occurs throughout the FI interval
and is not just restricted to one part of it, either the post-
reinforcement pause, as Schneider (1969) proposes, or the run time,
as Shull (1979) claims.

It would be expected, if the pattern of responding on
FI does reflect the left-hand side of a temporal generalisation
gradient, that, if reinforcement was occasionally omitted at the
end of the fixed interval, the elusive right-hand side would
materialise forming an inverted U-shaped temporal generalization
gradient in terms of local rates of responding over the point
where reinforcement was due to be delivered. Attempts to produce
this right-hand side by means of omitting reinforcement have not,
so far, met with much success (cf Staddon and Innis 1969 ;
Zimmerman 1971). Probably the most successful attempt was one
by Catania and Reynolds (1968), themselves using an evenly probable
mixed FI 30 - FI 240 schedule with pigeons as subjects. They
found that there was a slight drop in the local rate of responding
on the long interval after the time at which reinforcement would
have been delivered at the end of the short interval. This,
however, was only observed with one of their animals to any extent.

It was noted in the last chapter, that on a schedule with
a large relative difference between the two intervals making up the
mixed FI, two of the rats showed an inverted U-shaped gradient of
local rates. It is thus proposed in this present chapter to

systematically investigate the performance maintained by mixed
FI schedules, in which there is a relatively large difference
between the two values making up the schedule.

The first experiment in this chapter was designed to
investigate the pattern of responding produced on a mixed FI
schedule, in which there were large differences between the two
intervals, and to find the relationship, if any, between the
pattern of responding and that observed on an FI schedule.

Experiment III

Method

Subjects.

Four naive male hooded rats, approximately 12 weeks'
old at the start of the experiment. They were individually housed
and maintained at 80% of their free-feeding weight throughout the
duration of the experiment. Water was freely available in the home
cages.

Apparatus.

The apparatus was the same as was used in Experiments
I and II.

Table 3.   Experiment 3 :

The condition on which the animals
were trained, given in the order in
which they were trained.   The number
of sessions of training, the mean
postreinforcement pause (PRP) and the
standard deviation of the pauses (SD)
are also given for each animal on each
condition.

Table 3.

Animal	Schedule	Number of Sessions	Postreinforcement Pause	
			Mean	SD
R13	FI240 sec	32	105.25 sec	54.25 sec
	FI 30 sec	29	17.84 sec	7.80 sec
	Mixed FI 30-FI240 sec	51	23.06 sec	7.92 sec
	FI240 sec	32	109.90 sec	62.69 sec
	FI 30 sec	26	27.80 sec	8.01 sec
R14	FI240 sec	29	92.34 sec	38.60 sec
	FI 30 sec	29	26.43 sec	9.20 sec
	Mixed FI 30-FI240 sec	51	25.00 sec	6.26 sec
	FI240 sec	32	99.93 sec	44.83 sec
	FI 30 sec	26	23.74 sec	7.26 sec
R15	FI240 sec	32	113.78 sec	55.30 sec
	FI 30 sec	29	20.01 sec	6.41 sec
	Mixed FI 30-FI240 sec	53	12.66 sec	5.62 sec
	FI240 sec	32	115.32 sec	56.24 sec
	FI 30 sec	23	18.30 sec	6.62 sec
R16	FI240 sec	32	125.81 sec	53.26 sec
	FI 30 sec	28	18.24 sec	6.90 sec
	Mixed FI 30-FI240 sec	50	34.21 sec	12.93 sec
	FI240 sec	34	146.12 sec	52.33 sec
	FI 30 sec	24	29.01 sec	6.96 sec

Procedure.

Lever-pressing responses were shaped in the first session, the animals were then allowed to obtain 60 contingent reinforcements on a CRF schedule. After this preliminary training the animals were trained on two baseline FI schedules, FI 240 and then FI 30. This was then followed by training on an evenly probable mixed FI 30 - FI 240 schedule. They were then retrained on the two FI baseline schedules FI 240 followed by FI 30. The number of sessions used for training in each condition is given in Table 3. Training in all conditions was continued until performance was stable.

Results and Discussion.

Figure 13 shows the postreinforcement pause for each animal on each of the conditions. The pause produced on the mixed FI 30 - FI 240 condition was virtually the same as the pause produced on the FI 30-sec condition. This finding is consistent with the major finding in the last chapter, that the pause is almost entirely determined by the duration of the short interval in a mixed FI schedule.

A further analysis was conducted on the postreinforcement pause produced on the mixed FI schedule, to ascertain whether or not it was affected by being preceded by a run of consecutive long intervals. (With the procedure used it was comparatively unlikely

Figure 13. Experiment 3 :

The postreinforcement pause on all

the conditions in order, FI 240-sec (A),

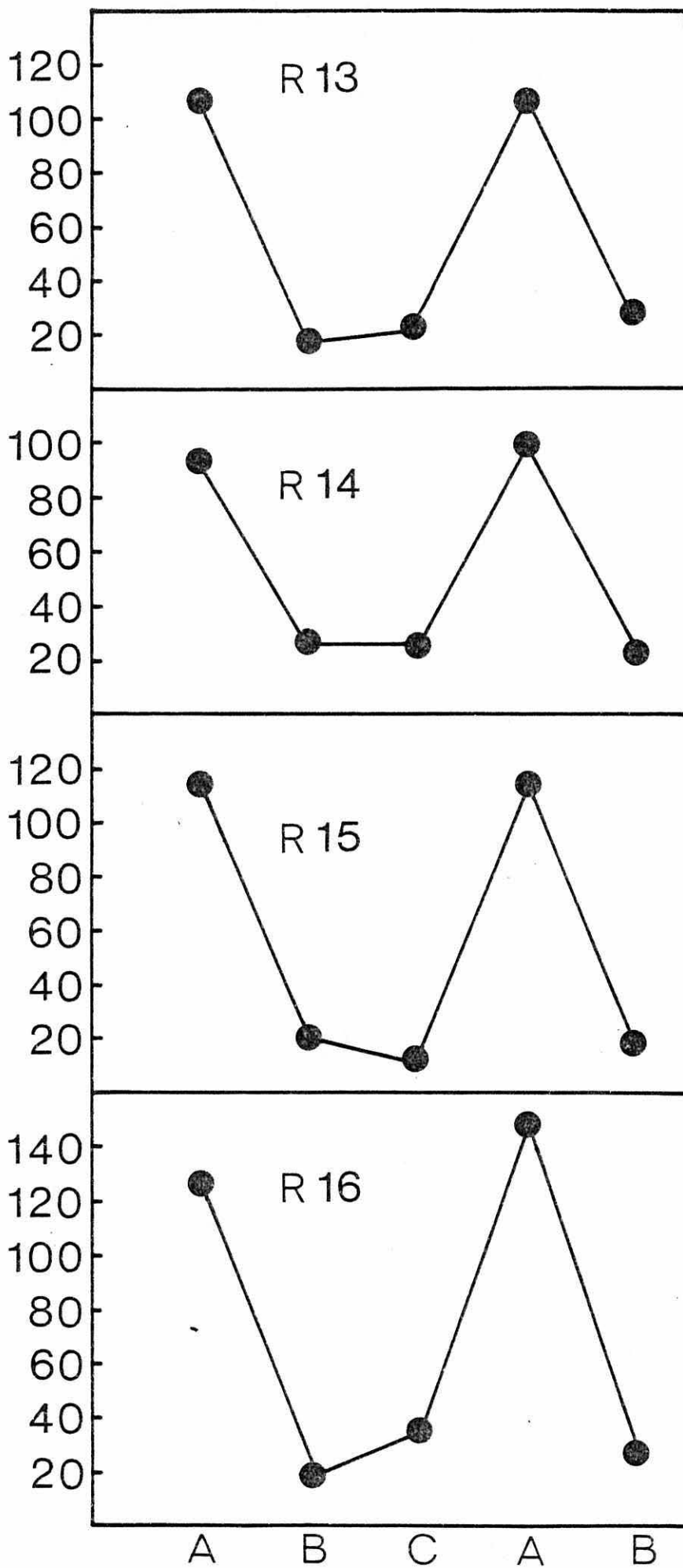FI 30-sec (B) and Mixed FI 30 - FI 240-sec (C).

Table 4.   Experiment 3 :

A Sanova, one way analysis and variance for
uneven groups of observations, performed on
groups of postreinforcement pause duration,
classified according to whether they were
preceded by, one, two, three or four
consecutive long intervals.   The table shows,
for both within and between groups, the sum
of squares (SS), the degrees of freedom (df),
the mean square (MS), the F value and whether
F is significant at the 5% level (NS or $P < .05$).

Table 4.

Animal 13

Source of Variation	SS	df	MS	F	P
Between groups	22.7	3	7.57	0.18	N.S.
Within groups	6,072.93	143	42.47		

Animal 14

Source of Variation	SS	df	MS	F	P
Between groups	2,003.41	3	667.81	3.90	P ·0.5
Within groups	22,629.22	132	171.43		

Animal 15

Source of Variation	SS	df	MS	F	P
Between groups	158.73	3	52.91	1.52	N.S.
Within groups	4,282.42	123	34.82		

Animal 16

Source of Variation	SS	df	MS	F	P
Between groups	1.01	3	0.335	0.008	N.S.
Within groups	5,850.38	131	44.66		

that any interval would be preceded by a run of five consecutive
long intervals, though it would be expected that several intervals
a session would be preceded by a run of four consecutive long
intervals). The pauses on each session, from which data were
taken, were categorised into groups depending upon whether they
were preceded by one, two, three or four consecutive long intervals.
It would be expected, that if these runs of consecutive long intervals
were having an effect upon the duration of the pause, that there
would be a significant increase in the duration of pauses as the
number of long intervals preceding them increased (cf Spencer 1978).
An analysis of variance was conducted to check whether there were
significant differences between these groups of pauses ;
analyses were conducted for each animal separately. The results
of these analyses are given in Table 4. Only Animal R14 is
significant at the 5% level, Animal R13 and R16 being
non-significant. It may be concluded that there is no reason to
suppose there is any local effect upon the duration of the post-
reinforcement pause due to runs of up to four consecutive long
intervals. It is also unlikely that a run of consecutive short
intervals will affect the duration of the postreinforcement pause,
since the mean pause found on the mixed FI schedule can be seen not
to differ from that produced by an FI of value equal to the short
interval, and is hence unlikely to be reduced further. These
findings cast doubt on Shull's (1971a; 1979) suggestion that the
duration of the postreinforcement pause is determined by the

Figure 14.   Experiment 3 :

The local rate of responding across

the long interval of mixed FI 30 -

FI 240-sec (filled squares) and the

local rate of responding in the second

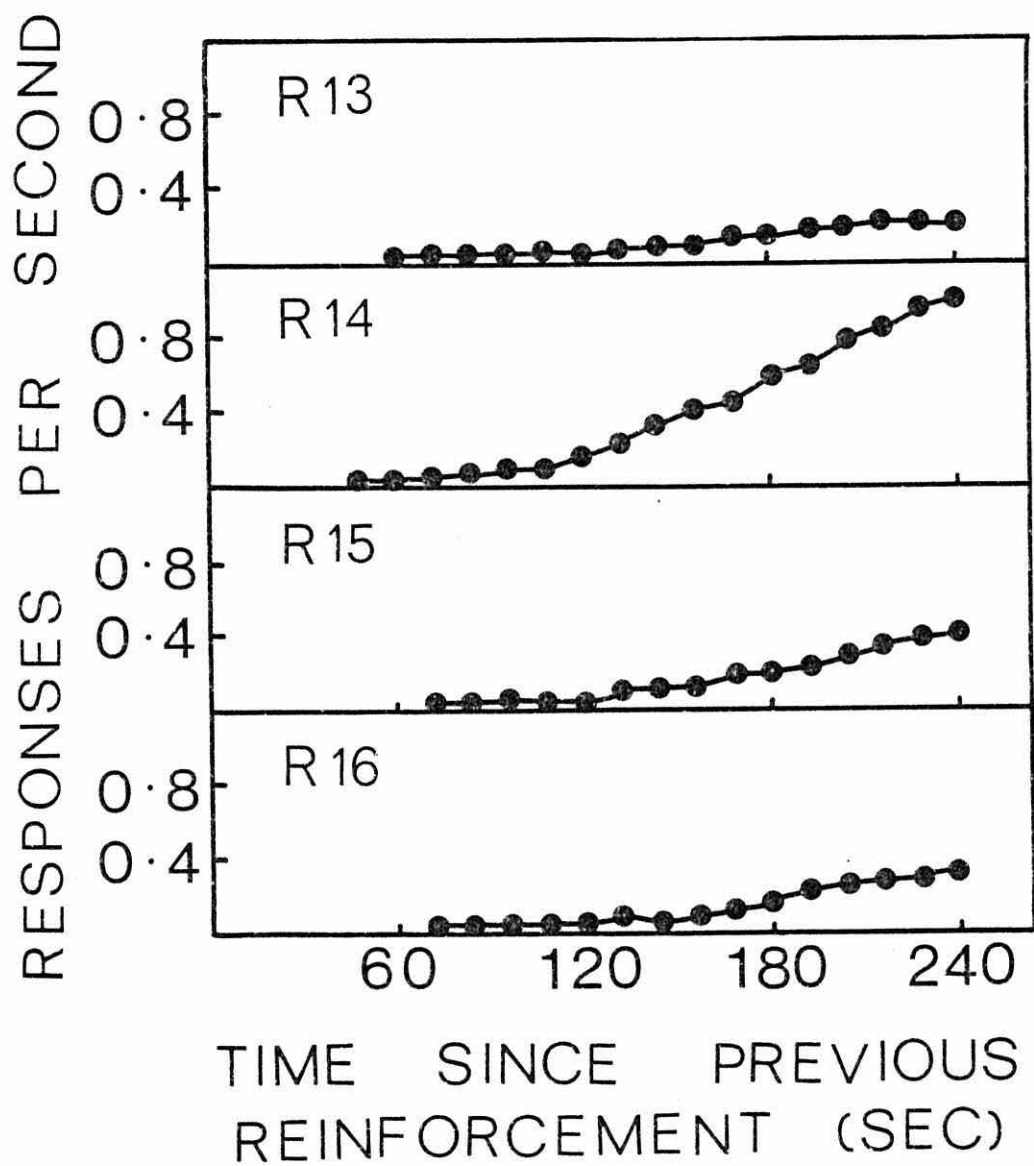FI 240-sec baseline condition (unfilled
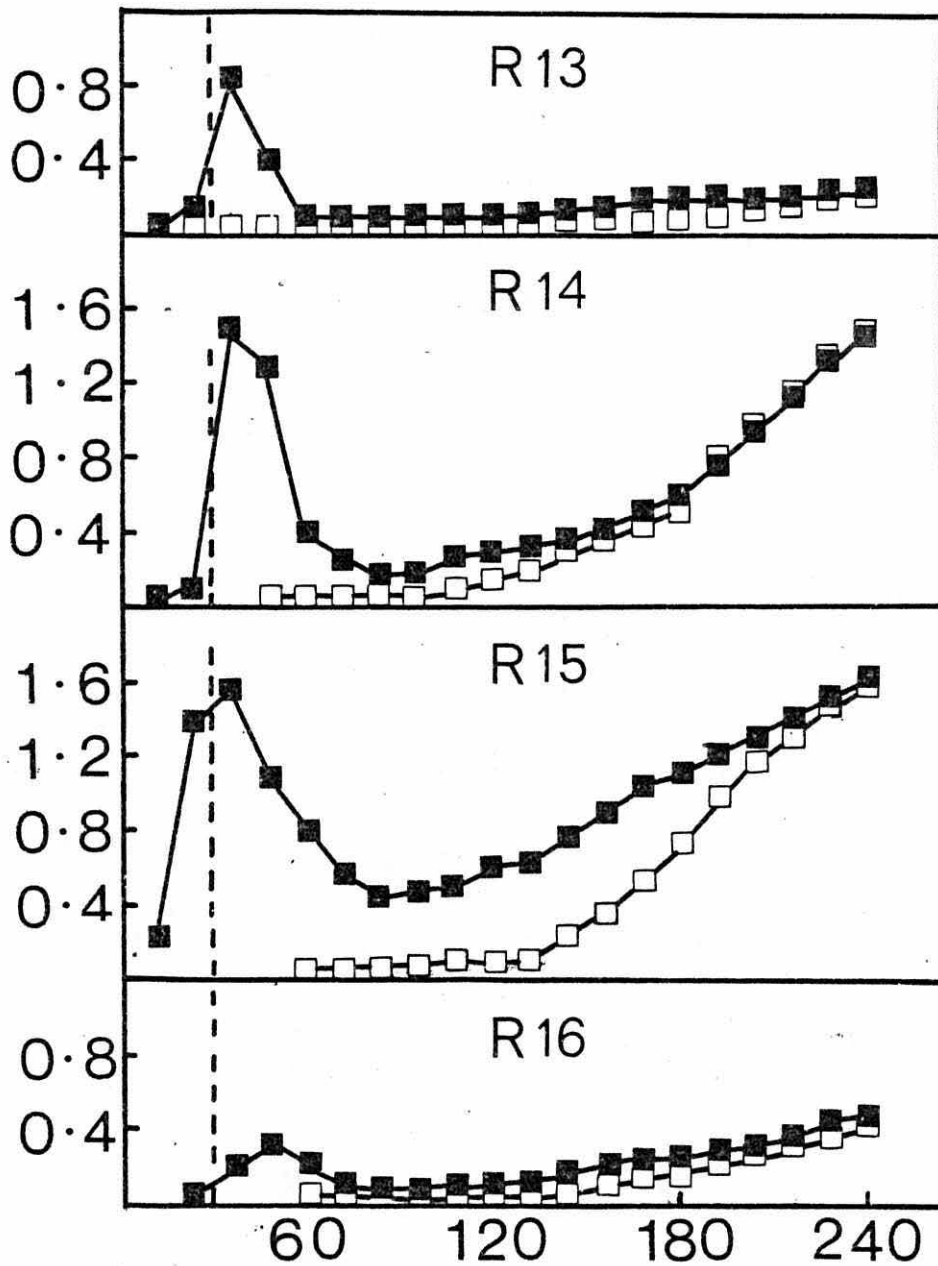
squares), for all four subjects.

Figure 15.   Experiment 3 :

The local rate of responding across

the first baseline FI 240-sec condition,

for all four subjects.

duration of the preceding run time. It would seem that the pause

must be a function of the duration of many preceding intervals,

and it is not affected by minor variations in the density of a

particular interreinforcement interval (cf Staddon 1974).

Figure 14 shows the local rate of responding across the

long interval df the mixed FI schedule (filled squares) and the

local rate of responding in the second FI 240 baseline condition

(unfilled squares) both in terms of twenty 12-sec bins.   (The

performance on the first baseline FI 240 condition is shown in

Figure 15).   Each animal is represented separately.   The broken

vertical line marks the end of the 30-sec interval.

It can be seen quite clearly from these graphs that each

animal produced an inverted U-shaped distribution of local rate of

responding, centred about a point slightly to the right of the

30-sec mark.   The other notable feature of these graphs is the

similarity between the local rate of responding in the mixed FI and

the FI 240-sec baseline schedule after about 120-sec into the long

interval.   This finding would suggest that having a probability of

reinforcement at the beginning of an interval has very little effect

upon the animal's behaviour towards the end of the interval.

Figure 16 again shows the local rate of responding of the

long interval in the mixed FI (filled squares), but this time only

the first half, in terms of twenty, 6-sec bins.   The unfilled

Figure 16.   Experiment 3 :

The local rate of responding across

the first half of the long interval

of the mixed FI (filled squares) and

the local rate of responding in the

second FI 30 baseline condition

(unfilled squares) for all four

subjects.

RESPONSES PER SECOND

R 13

R 14

R 15

R 16

TIME SINCE PREVIOUS
REINFORCEMENT (SEC)
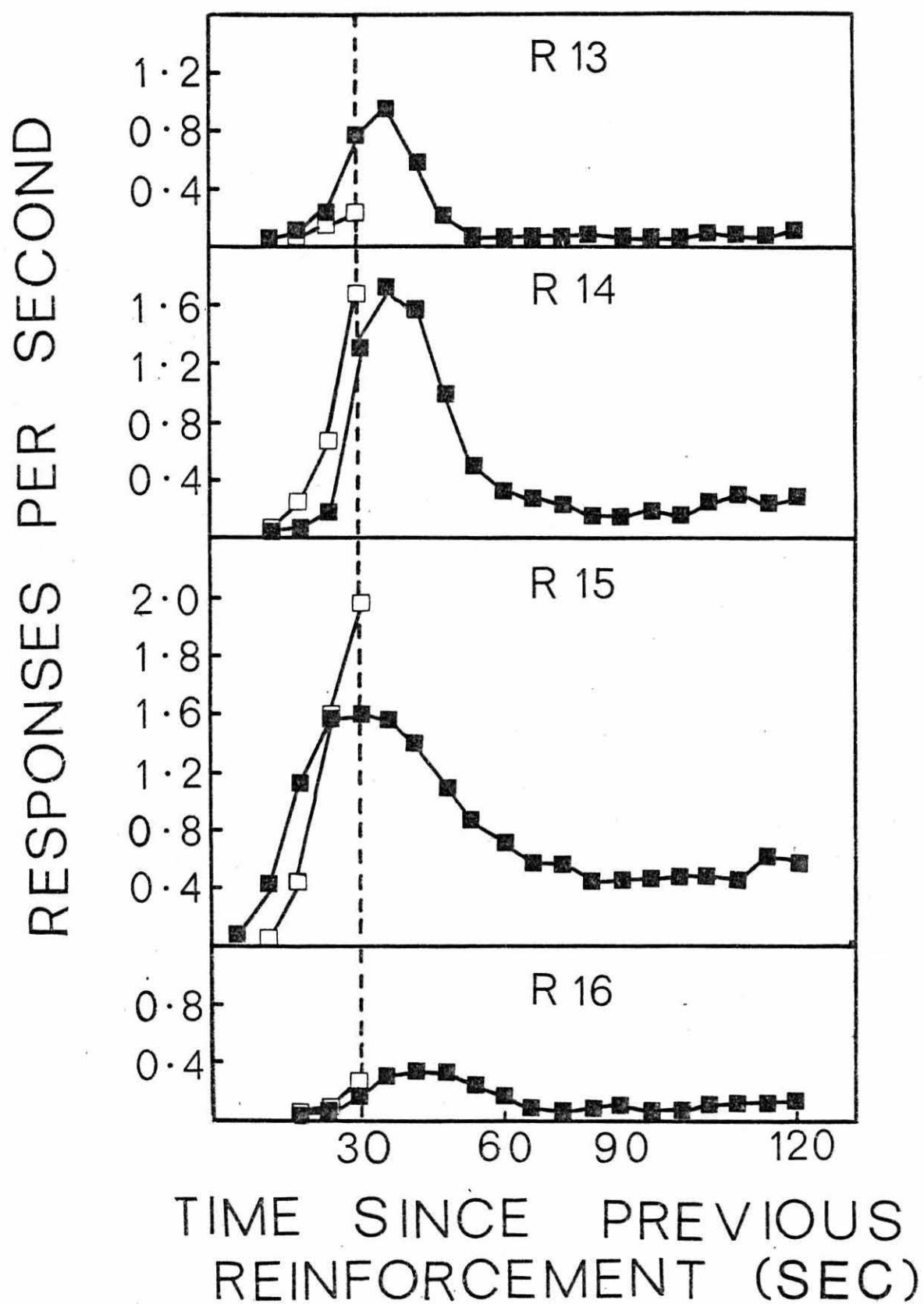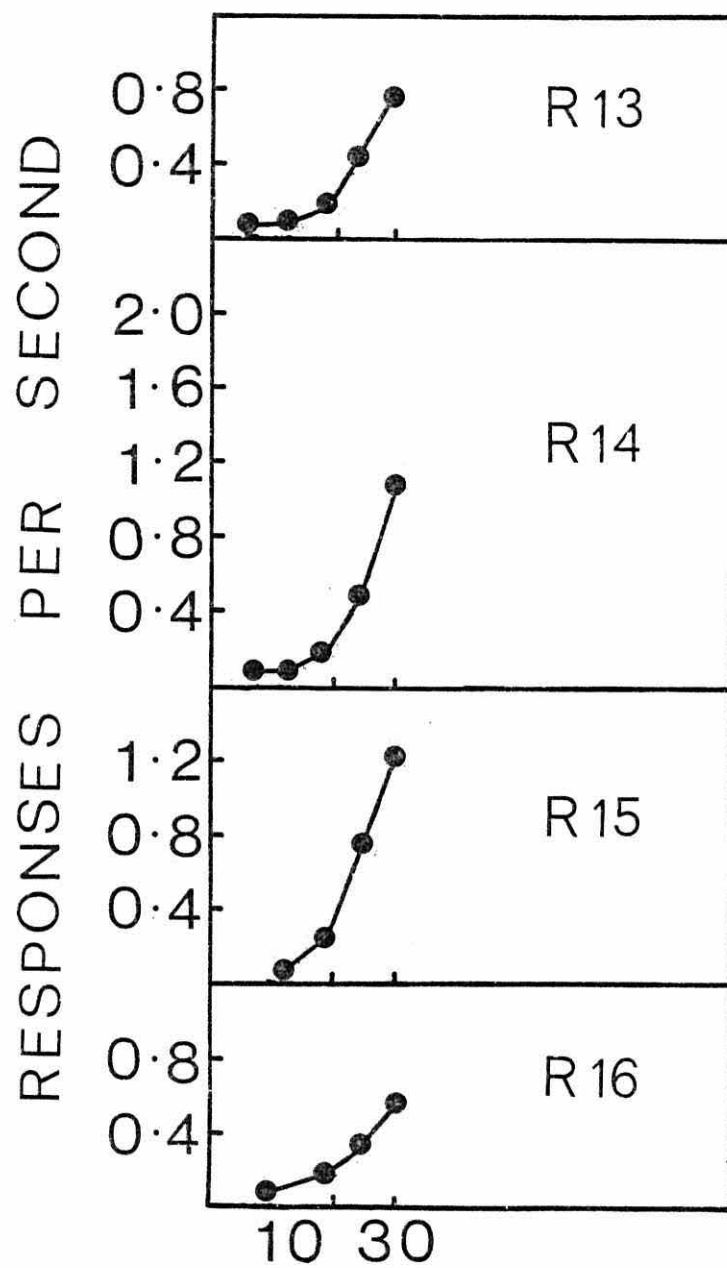
Figure 17.   Experiment 3 :

The local rate of responding across

the first baseline FI 30-sec condition

for all four subjects.

RESPONSES PER SECOND

R 13

R 14

R 15

R 16

TIME SINCE PREVIOUS
REINFORCEMENT (SEC)

squares represent the local rate of responding of the second
FI 30 baseline schedule. (The first baseline FI 30 schedule
performance is shown in Figure 17). The broken vertical line
again denotes the 30-sec point. In Figure 16 the inverted U-shaped
distribution can be seen in more detail than in Figure 14. Apart
from R15 it appears to be symmetrical in shape and have something
of the appearance of a normal distribution. This symmetry would
seem to give support to Catania and Reynolds' suggestion that the
spread of effect of a reinforcement upon the local rate of responding
could be considered as a gradient of temporal generalization.

Again, it can be seen that the local rate of responding
in the FI 30-sec baseline conditions did not systematically differ
from the local rate of responding in the first 30-sec of the long
interval of the mixed FI schedule. This lends further support to
the finding in the last chapter that a probability of 0.5 of
reinforcement being delivered will tend to maintain a similar local
rate of responding as a probability of 1.0, provided that there is
a large enough difference between the two opportunities for
reinforcement. It would, therefore, seem that the pattern of
responding on an evenly probable mixed FI schedule up to the end
of the short interval, is essentially the same as that on an
ordinary FI schedule.

The results of this experiment, so far, would seem to support Catania and Reynolds' hypothesis as to pattern of responding maintained by a reinforcement at a particular point in time being due to temporal generalization. However, an alternative explanation, similar to Schneider's (1969) two-state analysis, could be offered. The animals could pause for a discriminated amount of time and then respond at a constant rate using the number of responses that it emits as a disciminative stimulus as to whether or not reinforcement is to be delivered at the end of the short interval. Figures 18 to 21 show a further analysis of the data, which excludes the postreinforcement pause for each animal. The intervals were divided up into groups, depending upon how soon after reinforcement the first response was made. This analysis is similar to that used by Dewes (1978).

Figure 18 shows the variation in the rate of responding for the individual groups of intervals across the first 120 seconds at the long interval in the mixed FI, for animal R13. A striking feature of this graph is that the initial local rate of responding for each group reflects the position in the interval. This is consistent with an earlier finding by Lowe and Harzem (1977) who found, by analysis of the first few IRTs produced in an FI interval, that a rat's initial rate of responding was greater, the later in the interval responding started. This finding is strongly suggestive of temporal discrimination occurring during the

Figure 18.   Experiment 3 :

An analysis of the changes in the running

rate of intervals for Animal R13.   The

intervals were divided up into groups,

depending upon which 6-sec 'bib' responding

started in.   The lines represent the

mean rate of responding across all

subsequent bins for the first half of the

long interval.

R 13

Figure 19.   Experiment 3 :

An analysis of the changes in the running

rate of intervals for Animal R14.   The

intervals were divided up into groups,

depending upon which 6-sec 'bin' responding

started in.   The lines represent the

mean rate of responding across all

subsequent bins for the first half of the

long interval.
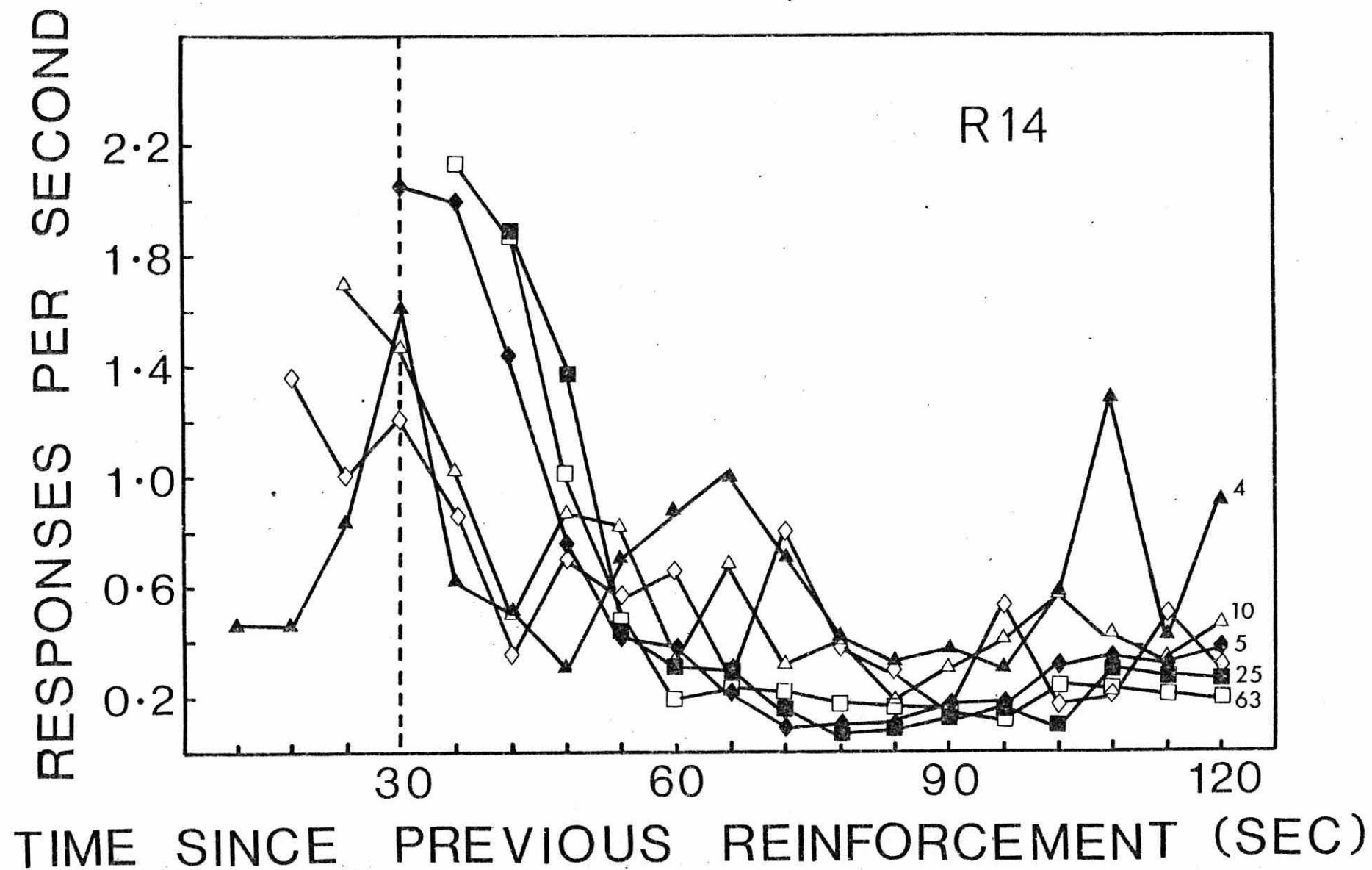
Figure 20.   Experiment 3 :

An analysis of the changes in the running

rate of intervals for Animal R15.   The

intervals were divided up into groups,

depending upon which 6-sec 'bin' responding

started in.   The lines represent the mean

rate of responding across all subsequent

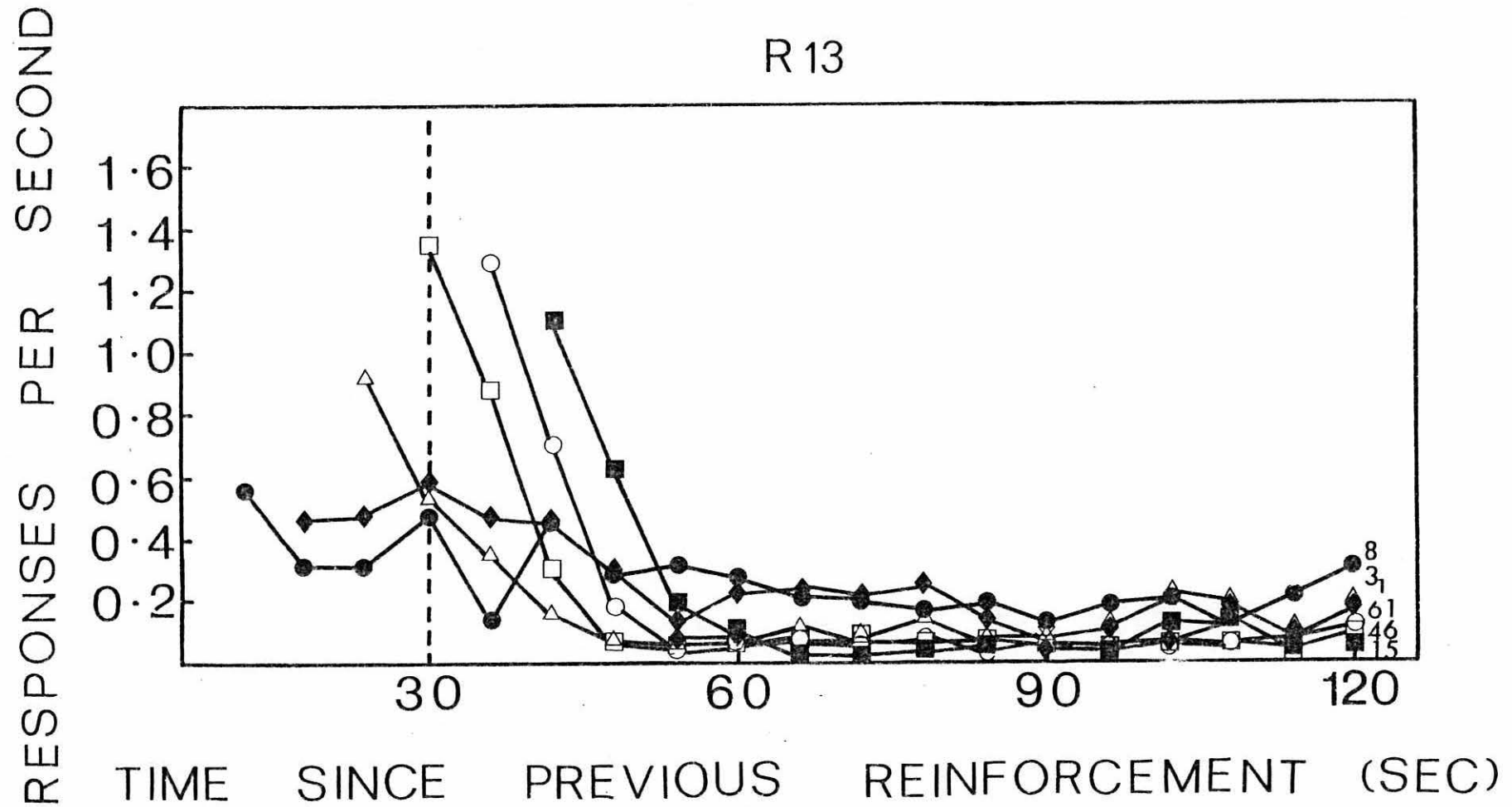bins for the first half of the long interval.

Figure 21.   Experiment 3 :

An analysis of the changes in the running

rate of intervals for Animal R16.   The

intervals were divided up into groups,

depending upon which 6-sec 'bin' responding

started in.   The lines represent the mean

rate of responding across all subsequent

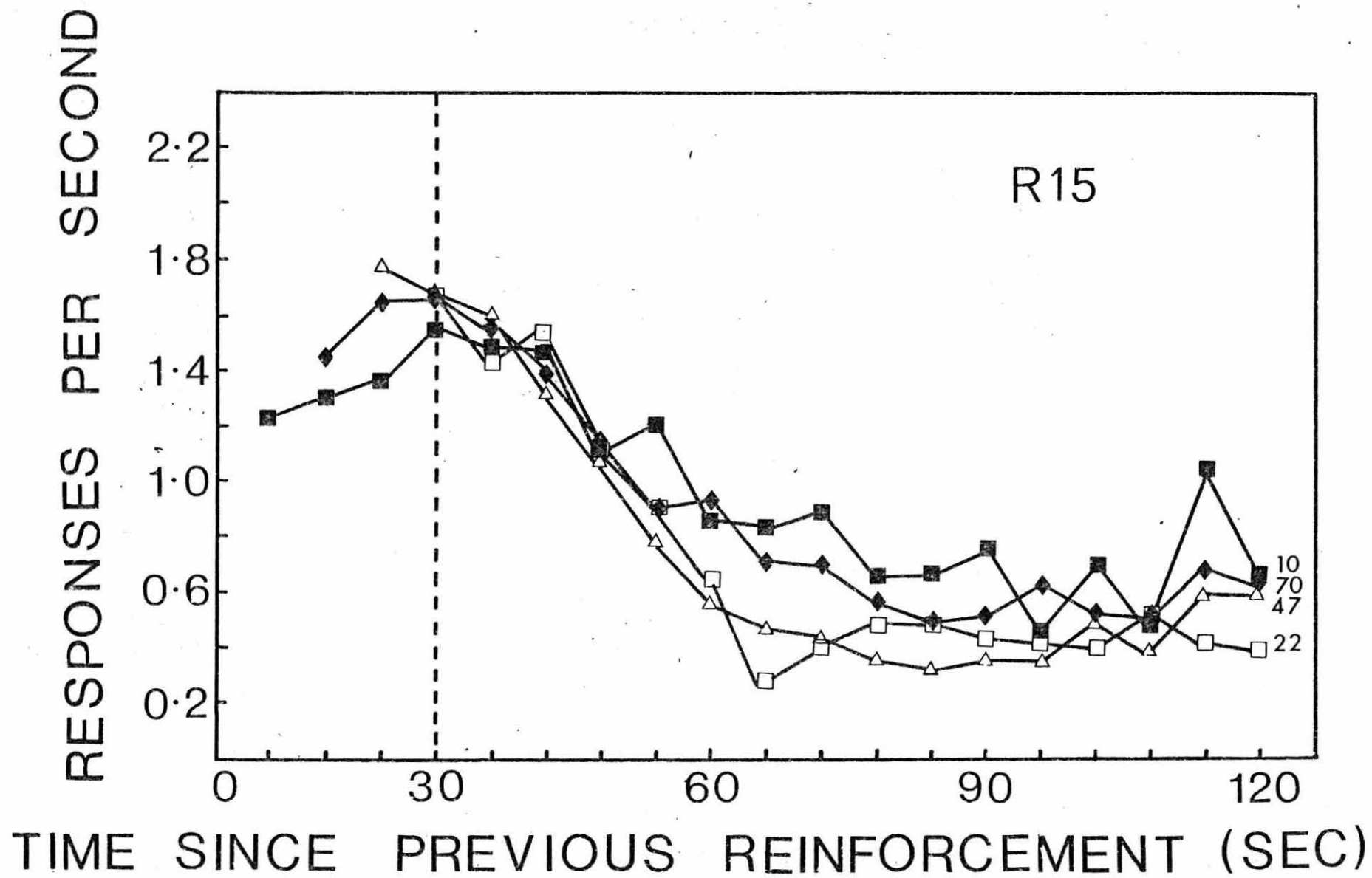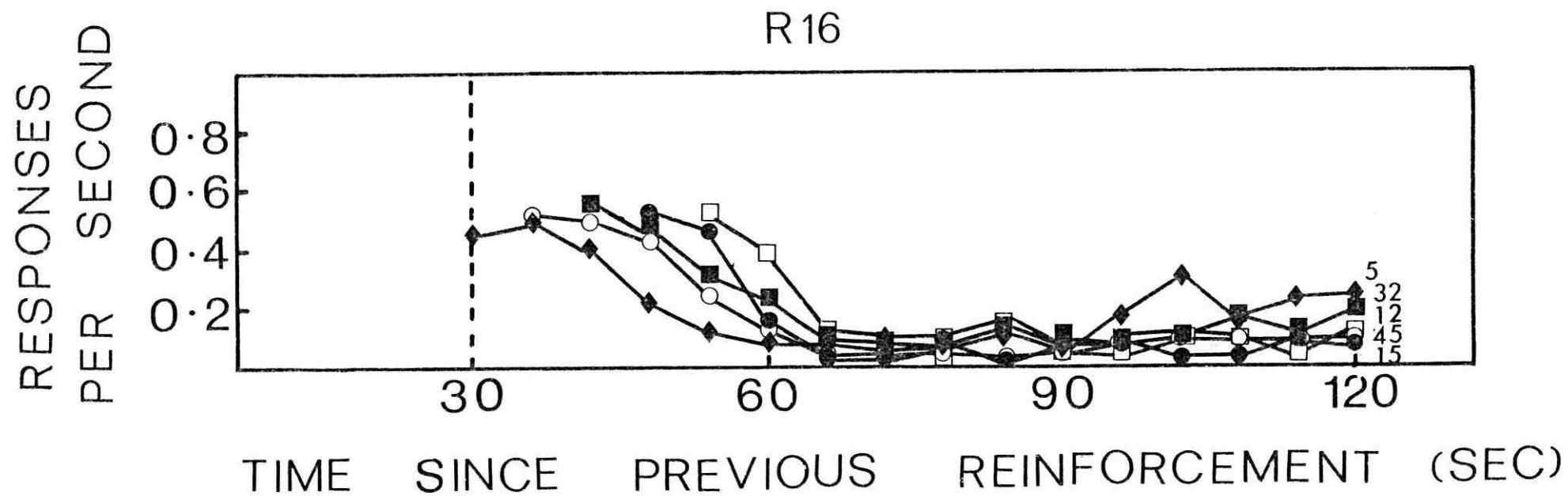bins for the first half of the long interval.

R 16

postreinforcement pause time, which is inconsistent with Shull's
(1979) account of FI responding. It may also be seen from this
graph that once responding had started, there is not a constant
rate of responding. The groups of intervals, in which responding
started early in the interval, tended to increase in local rate of
responding, until the point at which reinforcement would be
delivered at the end of the short interval, and then decreases.
With those groups of intervals in which responding started later
in the interval, there was a steady decrease in the rate of
responding as the time from the point at which reinforcement would
be delivered increases.

Figure 19 shows this analysis for Animal R14. It can be
seen that it shows the same pattern of responding within the run time
as did Figure 18, in all essential respects. What is of particular
note with this animal was that the decrease in rate of responding
becomes more rapid the later responding started in the interval.

Figure 20 shows the analysis for Animal R15. With this
figure it can be seen quite clearly that local rate of responding,
within the intervals, in which responding started soon after
reinforcement, increased until the time at which reinforcement would
have been delivered at the end of the short interval and then
decreased.

The analysis carried out for Animal R16 is shown in
Figure 21. This animal tended to produce long postreinforcement

Figure 22.   Experiment 3 :

A section of typical cumulative record

for each animal taken from the mixed FI 30 -

FI 240-sec schedule condition.

R13

R15

300 RESPONSES

R14

R16

20 MINUTES
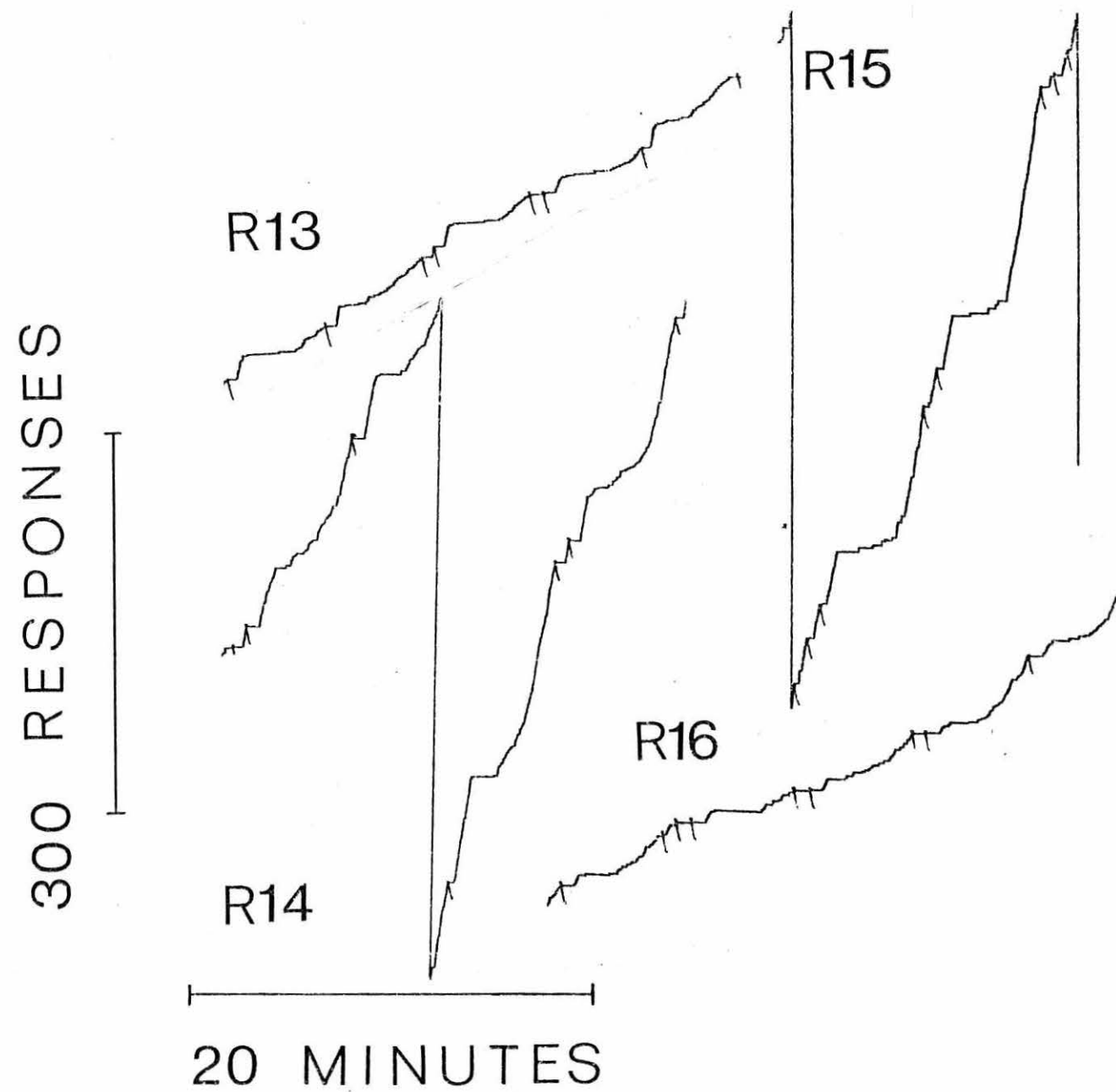
pauses and there is, therefore, no data for variations in the running rate before the end of the short interval. For the intervals that are shown, the initial change in the rate of responding seems to have something of the appearance of a normal distribution, again with the deceleration in rate within an interval, depending upon how late within the interval responding started.

This analysis taken as a whole for all four animals shows that there is a variation in the rate of responding during the run time which depends upon the time that has elapsed since reinforcement.

Figure 22 shows a section of typical cumulative record for each of the animals. A notable feature of these records is the S-shaped early part of the long interval, being particularly noticeable with Animal R14. This S-shaped pattern of responding is the cumulative form of the inverted U-shaped distribution seen in Figures 14 and 16. These cumulative records, taken together with the analyses of the rate of responding during the run time, show that the acceleration and deceleration of the local rates of responding, observed in Figures 14 and 16, reflect the pattern of responding within individual intervals and are not just artifacts of averaging different postreinforcement pauses.

The next experiment was designed to assess any influences that the long interval may have upon the pattern of responding occurring on an evenly probable mixed FI, in which the difference between the intervals is comparatively large.

Experiment IV

Method

Subjects.

The same four rats that were used in Experiment III served as subjects in this experiment.

Apparatus.

The apparatus was as described in Chapter 4 on experimental methods. The operant chambers used in this experiment were four Lehigh Valley model RTC-028.

Procedure.

The animals were first trained on an FI 30-sec schedule, until they were considered stable. They were then trained on

Table 5.   Experiment 4 :

The condition on which the animals
were trained, given in the order in
which they were trained.   The number
of sessions of training, the mean
postreinforcement pause (PRP) and the
standard deviation of the pauses (SD)
are also given for each animal on each
condition.

Table 5.

Animal	Schedule	Number of Sessions	Postreinforcement Pause	
			Mean	SD
R13	FI30 sec	30	31.15 sec	9.44 sec
	Mixed FI30-FI120 sec	25	31.13 sec	7.78 sec
	Mixed FI30-FI 60 sec	25	28.35 sec	8.31 sec
	Mixed FI30-FI240 sec	25	25.92 sec	9.61 sec
	Mixed FI30-FI 45 sec	30	25.78 sec	9.56 sec
	Mixed FI30-FI480 sec	25	25.15 sec	13.97 sec
	FI30 sec	25	30.36 sec	6.93 sec
	Mixed FI30-FI240 sec	25	32.63 sec	11.34 sec
R14	FI30 sec	30	25.24 sec	8.93 sec
	Mixed FI30-FI120 sec	25	25.67 sec	6.74 sec
	Mixed FI30-FI 60 sec	25	25.64 sec	6.99 sec
	Mixed FI30-FI240 sec	25	22.46 sec	7.24 sec
	Mixed FI30-FI 45 sec	30	23.08 sec	9.64 sec
	Mixed FI30-FI480 sec	25	23.76 sec	6.44 sec
	FI30 sec	25	25.30 sec	8.42 sec
	Mixed FI30-FI240 sec	25	22.46 sec	5.69 sec
R15	FI30 sec	30	19.58 sec	10.01 sec
	Mixed FI30-FI120 sec	25	23.18 sec	6.13 sec
	Mixed FI30-FI 60 sec	25	25.72 sec	7.19 sec
	Mixed FI30-FI240 sec	25	26.68 sec	8.14 sec
	Mixed FI30-FI 45 sec	30	31.27 sec	10.01 sec
R16	FI30 sec	30	28.10 sec	7.63 sec
	Mixed FI30-FI120 sec	25	29.80 sec	7.71 sec
	Mixed FI30-FI 60 sec	25	22.59 sec	5.74 sec
	Mixed FI30-FI240 sec	25	14.60 sec	7.36 sec
	Mixed FI30-FI 45 sec	30	29.23 sec	7.44 sec
	Mixed FI30-FI480 sec	25	40.81 sec	46.86 sec
	FI30 sec	25		

several evenly probable two-valued mixed FI schedules, in which
the short interval was always 30-sec and the long interval (n)
varied between 45-sec and 480-sec. Two redetermination conditions
were taken. The order and number of sessions the animals were
trained on in each schedule is given in Table 5.

Results and Discussion.

Figure 23 shows data for the postreinforcement pause
(left panel) and the overall rate of responding up to the end of the
short interval (right panel). Although there was considerable
random variation in both of these measures, there was no systematic
change in either measure with changes in the value of the long
interval. This would indicate that the short interval was acting
virtually independently of the long interval over the duration of
the short interval. This finding is consistent with the findings
of the earlier experiments reported in this thesis.

Figure 24 shows the local rates of responding for Animal
13 on all the conditions, the broken vertical line again denotes
the end of the short interval at the 30-sec point. The development
of the inverted U-shaped gradient can be quite clearly seen as the
long interval value increases. There was just a hint of a
deceleration after the 30-sec mark on the mixed FI 30 - FI 60
condition ; the distribution appearing in a complete form in the

Figure 23.   Experiment 4 :

The postreinforcement pauses (left panel)

and the overall rate of responding up to

the end of the short interval (right panel)

for all four animals, on each condition.
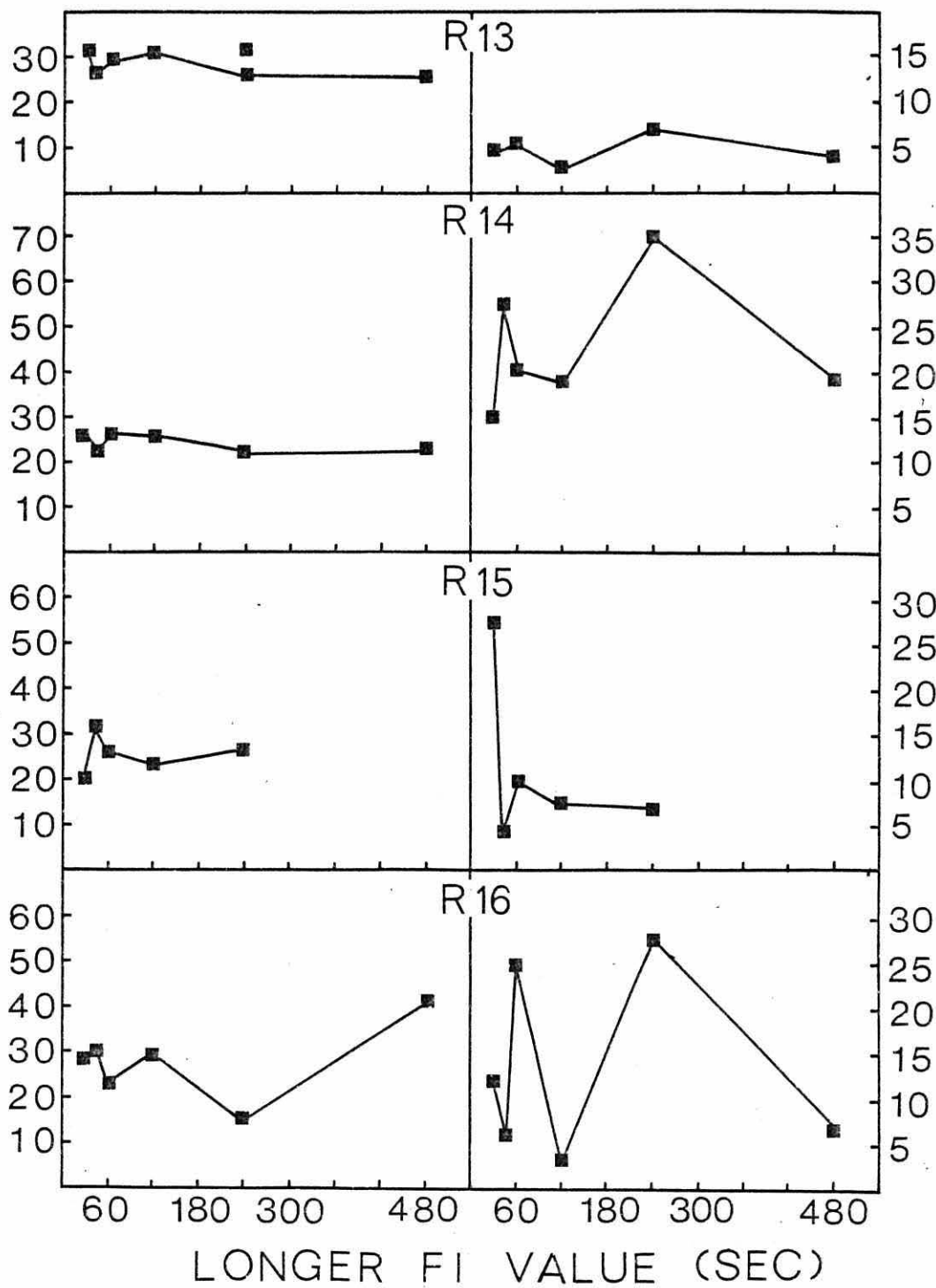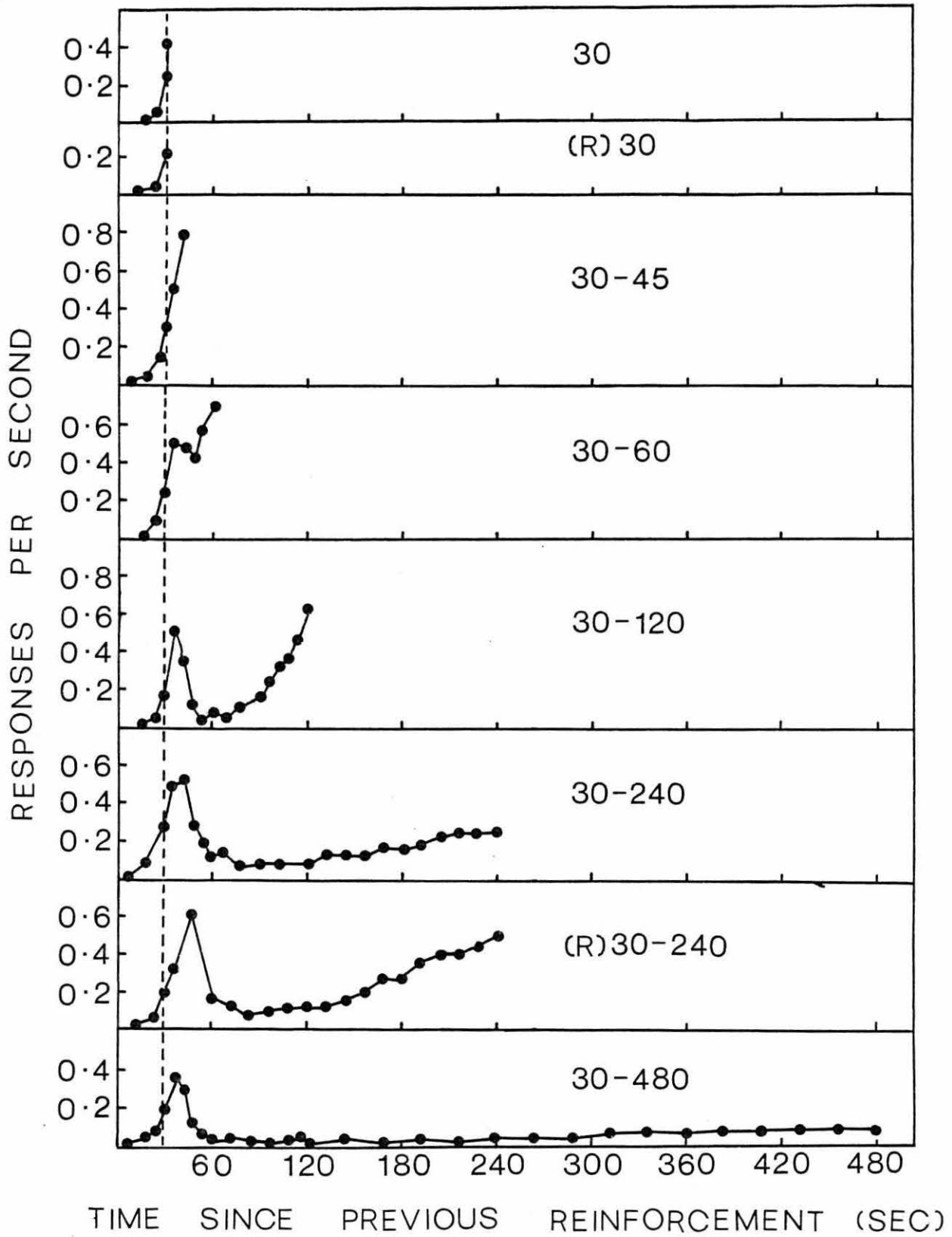
The unconnected points are redetermination

conditions.

Figure 24.   Experiment 4 :

The local rates of responding for

Animal R13 on all the conditions.

(R) shows redetermination conditions.

mixed FI 30 - FI 120 condition. It should also be noted that the peak of the distribution does not change systematically in the bottom three graphs in which the distribution had fully developed, suggesting that the long interval had very little influence upon the position of the distribution peak.

With Animal R14, Figure 25, the inverted U-shaped distribution was slightly more developed in the mixed FI 30 - FI 60 condition than it is for Animal R13. Again it is found that the distribution has fully developed by the mixed FI 30 - FI 120 condition, and that the peaks of the distributions, where they have developed, are situated one under the other.

Figures 26 and 27 show the performances of Animals R15 and R16, respectively. Unfortunately, both of these animals died before the experiment was completed, however, the data taken from these animals in the conditions on which they were trained is consistent with the findings for the other two animals. The distribution for both these animals developed by the mixed FI 30 - FI 120 condition and the peaks of the distributions can be seen to have been one under the other.

So far, from the results of this experiment, the following may be deduced. The inverted U-shaped function develops as the ratio between the two intervals making up the mixed FI schedule increases, being present in all animals at mixed FI 30 - FI 120.

Figure 25.   Experiment 4 :

The local rates of responding for

Animal R14 on all the conditions.

(R) shows redetermination conditions.

R 14

RESPONSES PER SECOND

TIME SINCE PREVIOUS REINFORCEMENT (SEC)
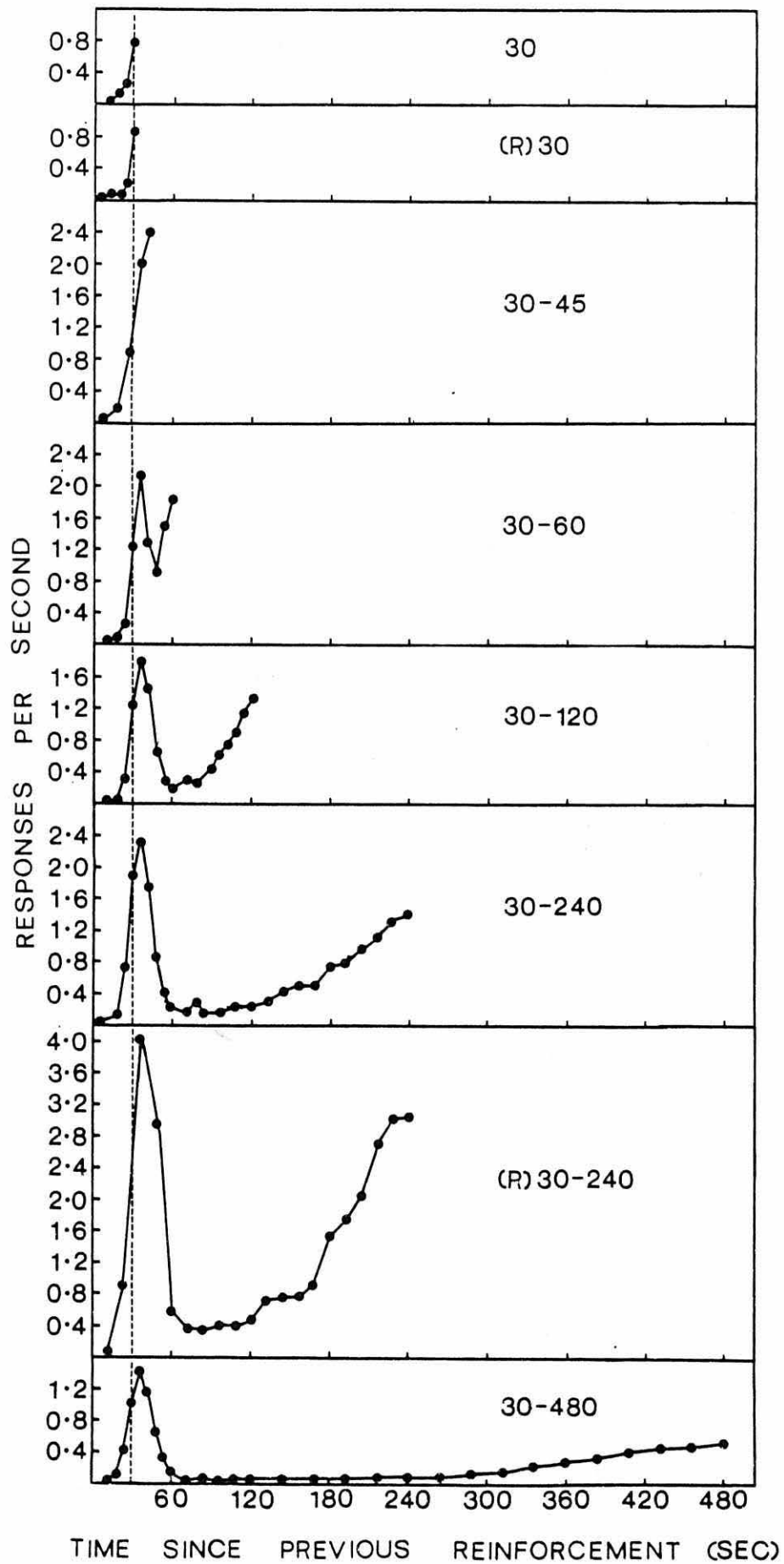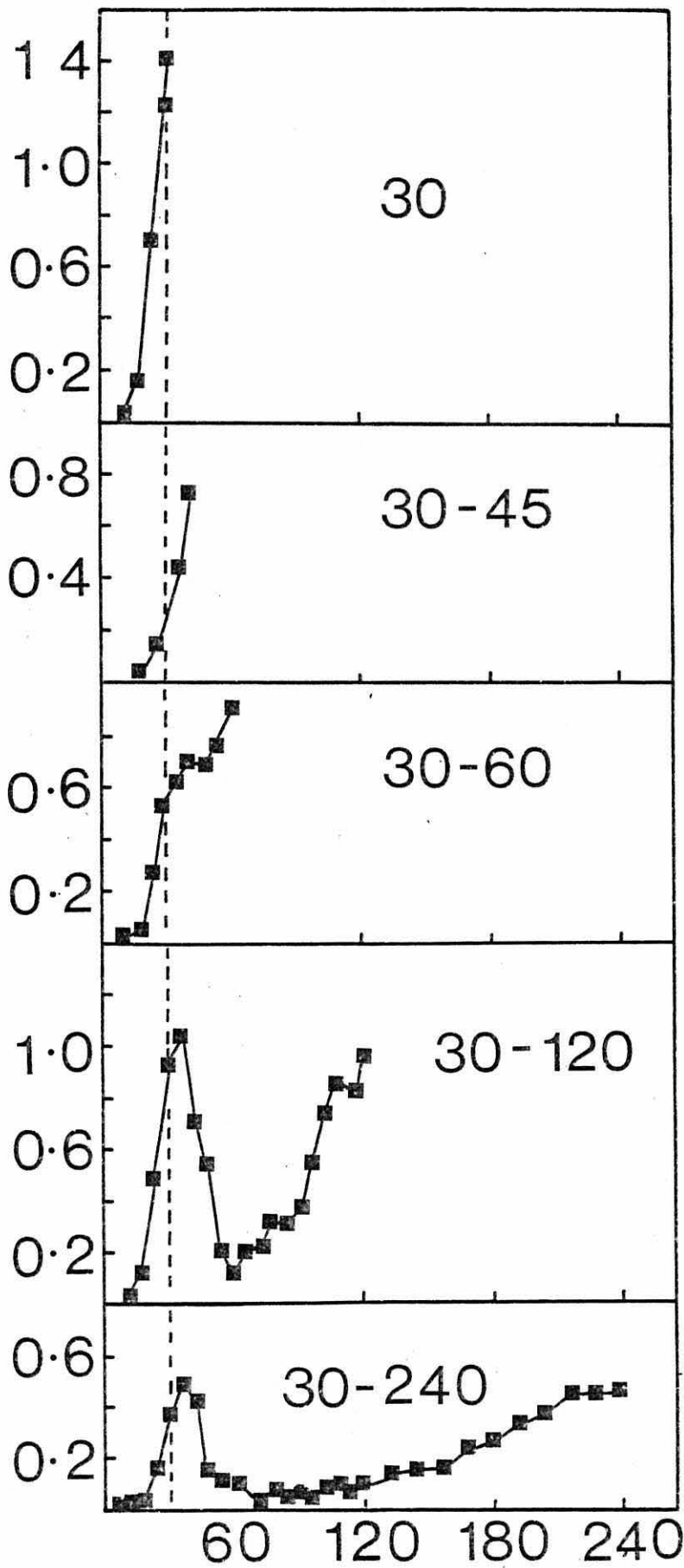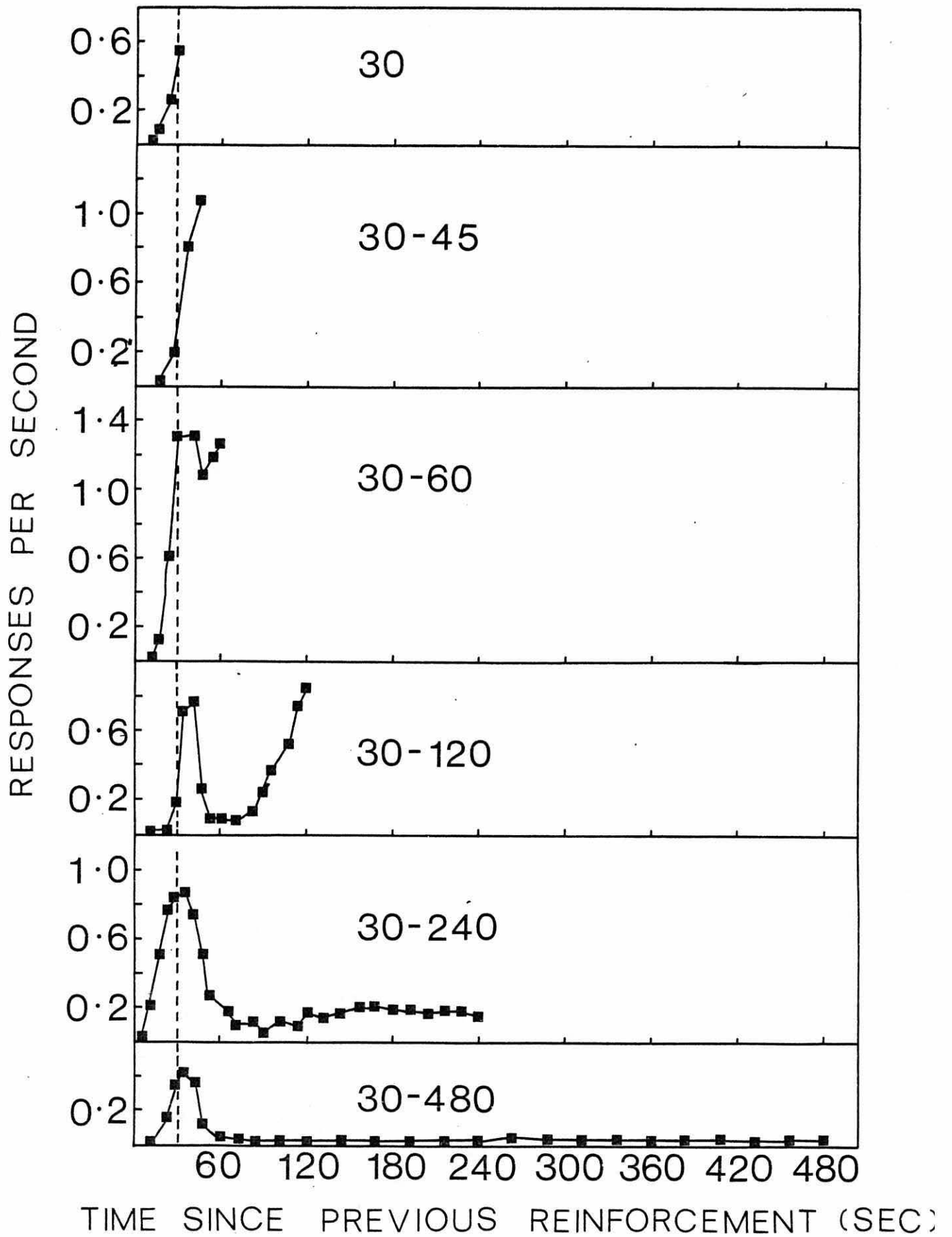
Figure 26.   Experiment 4 :

The local rates of responding for

Animal R15 on all the conditions.

(R) shows redetermination conditions.

Figure 27.   Experiment 4 :

The local rates of responding for

Animal R16 on all the conditions.

(R) shows redetermination conditions.

The peaks of the distribution are placed one under the other, showing that the long interval has no effect on the position of the peak. It may also be deduced that the long interval has no effect upon the variance of the distribution, since this measure does not change with changes in the long interval once the distribution has developed.

If this inverted U-shaped distribution is to be interpreted as a temporal generalization curve, it should comply with certain basic findings concerning the properties of both stimulus generalization and animal timing. The peak of the curve should be associated with stimulus paired with reinforcement, S+. Accordingly, the peak of the curve should systematically and proportionally increase with increases in the duration of the small interval. Secondly, it is now becoming a well documented finding that animal timing obeys Weber's law (Gibbon 1977 ; Stubbs 1968 ; 1979 ; Platt 1979 and Church 1978). Hence it would be expected that the spread of the distribution would be directly proportional to the time at which the peak of the distribution occurs, after reinforcement, and be proportional to the small interval in the mixed FI.

The final experiment in this chapter was designed to investigate these predictions by means of varying the duration of the short interval in the mixed FI, whilst keeping the long interval constant.

Experiment V

Method

Subjects.

Four, naive, male, hooded rats, approximately 12 weeks'
old at the start of the experiment. They were individually housed
and maintained at 80% of their free feeding weight throughout the
duration of the experiment. Water was freely available in the
home cages.

Apparatus.

The apparatus was described in Chapter 4 on experimental
method. The operant chambers used in this experiment were four
Lehigh Valley model 142 - 25.

Procedure.

Lever-pressing responses were shaped in the first session,
the animals were then allowed to have 60 contingent reinforcements
on a CRF schedule. After this preliminary training the animals
were trained on several evenly probable two-valued mixed FI schedules
in which the long interval was always 300-sec, and the short interval

Table 6.   Experiment 5 :

The condition which the animals
were trained, given in the order in
which they were trained.   The number
of sessions of training, the mean
postreinforcement pause (PRP) and the
standard deviation of the pauses (SD)
are also given for each animal on each
condition.

Table 6.

Animal	Schedule	Number of Sessions	Postreinforcement Pause	
			Mean	SD
R33	Mixed FI30-FI300 sec	30	24.57 sec	8.43 sec
	Mixed FI60-FI300 sec	25	49.50 sec	25.72 sec
	Mixed FI15-FI300 sec	25	13.78 sec	3.87 sec
	Mixed FI75-FI300 sec	25	48.46 sec	19.01 sec
	Mixed FI45-FI300 sec	25	34.68 sec	13.28 sec
	Mixed FI15-FI300 sec	25	17.99 sec	6.51 sec
	Mixed FI60-FI300 sec	25	46.67 sec	13.54 sec
R34	Mixed FI30-FI300 sec	30	16.33 sec	7.01 sec
	Mixed FI60-FI300 sec	25	26.95 sec	10.68 sec
	Mixed FI15-FI300 sec	25	11.41 sec	3.50 sec
	Mixed FI75-FI300 sec	25	32.12 sec	14.26 sec
	Mixed FI45-FI300 sec	25	26.49 sec	11.20 sec
	Mixed FI15-FI300 sec	25	11.76 sec	4.21 sec
	Mixed FI60-FI300 sec	25	36.01 sec	14.82 sec
R35	Mixed FI30-FI300 sec	30	16.09 sec	5,57 sec
	Mixed FI60-FI300 sec	25	32.66 sec	13.29 sec
	Mixed FI15-FI300 sec	25	9.28 sec	2.24 sec
	Mixed FI75-FI300 sec	25	42.27 sec	18.11 sec
	Mixed FI45-FI300 sec	25	33.22 sec	11.90 sec
	Mixed FI15-FI300 sec	25	18.74 sec	6.66 sec
	Mixed FI60-FI300 sec	25	41.67 sec	14.72 sec
R36	Mixed RI30-FI300 sec	30	27.90 sec	7.06 sec
	Mixed FI60-FI300 sec	25	54.65 sec	13.58 sec
	Mixed FI15-FI300 sec	25	26.26 sec	10.09 sec
	Mixed FI75-FI300 sec	25	72.55 sec	16.10 sec
	Mixed FI45-FI300 sec	25	47.25 sec	11.85 sec
	Mixed FI15-FI300 sec	25	44.70 sec	16.60 sec
	Mixed FI60-FI300 sec	25	65.45 sec	12.15 sec

varied between 15 and 75 seconds.   Details of the number of

sessions used and the order of conditions are given in Table 6.

Two redetermination conditions were also conducted.

Results and Discussion.

Figure 28 shows the postreinforcement pause for each

animal on each of the conditions (left panel) and the overall rate

of responding up to the end of the short interval.   The post-

reinforcement pause increased systematically with increases in the

short interval.   Since it would appear from the results of

Experiment III that the performance on a mixed FI schedule, up to

the end of the short interval is very similar to the performance on

an FI, this finding is consistent with the finding of Lowe, Harzem

and Spencer (1979) who have shown that there is a positive

relationship between the interval value and the duration of the

postreinforcement pause on an FI schedule.   The relationship

between the overall rate of responding up to the end of the short

interval and the duration of the short interval did not seem to be

regular, this was consistent with the findings of the other

experiments reported in this thesis where it has been found that

the overall rate of responding fluctuates over time regardless of

prior duration of training or changes of conditions.

Figure 28.   Experiment 5 :

The postreinforcement pause (left panel)
and the overall rate of responding up to
the end of the short interval (right panel)
for all four animals, on each condition.
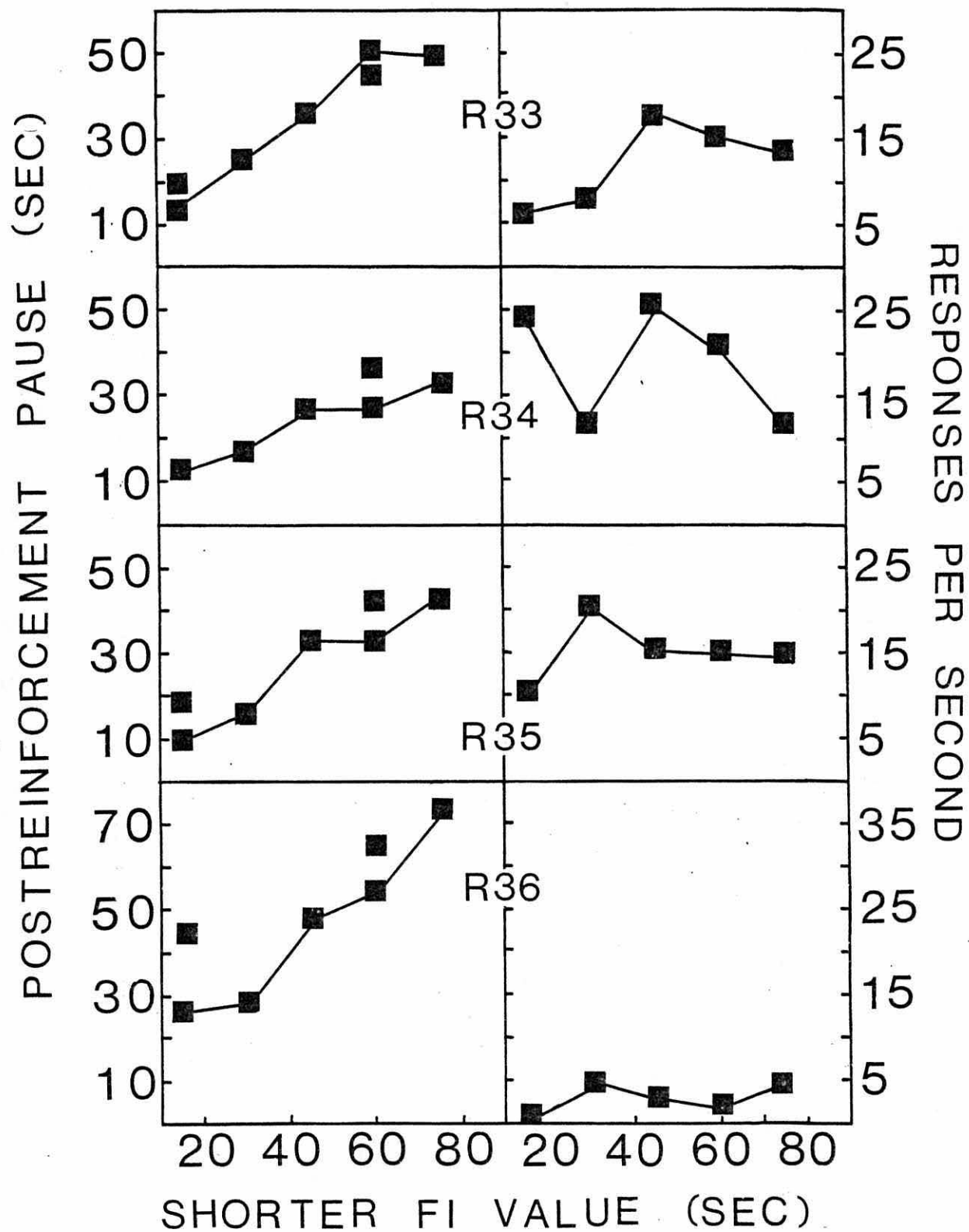The unconnected points are redetermination
conditions.

Figure 29 shows the performance of Animal R33 on all the
conditions. The left panel shows the local rate of responding
across the 300-sec of the long interval in terms of 20 15-sec bins.
The broken vertical line marks the end of the short interval. It
can be seen that the peak of the distribution moved over towards the
right of the graph as the short interval increased. Similarly,
variance of the distribution can be seen to have increased with
increases in the value of the short interval.

The right-hand panel again shows part of the local rate of
responding for each condition for this animal, but in this graph the
horizontal scale is proportional to the small interval of the
particular mixed FI. The bin size used in each case being $\frac{1}{4}$ of
the small interval. Thus, the top right-hand graph shows the first
part of the local rate of responding on mixed FI 15 - FI 300, in
terms of 10, 3.75-sec bins, the next one down shows the first part
of the local rate of responding of mixed FI 30 - FI 300, in terms
of 10, 7.5 sec bins and then continues for the rest. The broken
vertical line marks the point at which the short interval (n) ends
in each condition.

Observations of the right-hand panel give a more detailed
look at the relationship between the parameters of this distribution
and the duration of the small interval. The median, or the peak
of the distribution was always just to the right of the end of the
short interval, showing that the position of the peak was directly

Figure 29.   Experiment 5 :

The local rates of responding for Animal
R33 across the long interval of the mixed
FI (left panel) and the local rate of
responding of the early region of the
long interval plotted on a horizontal
scale, which was proportional to the
duration of the short interval, for each
condition.   (R) shows a redetermination
condition.
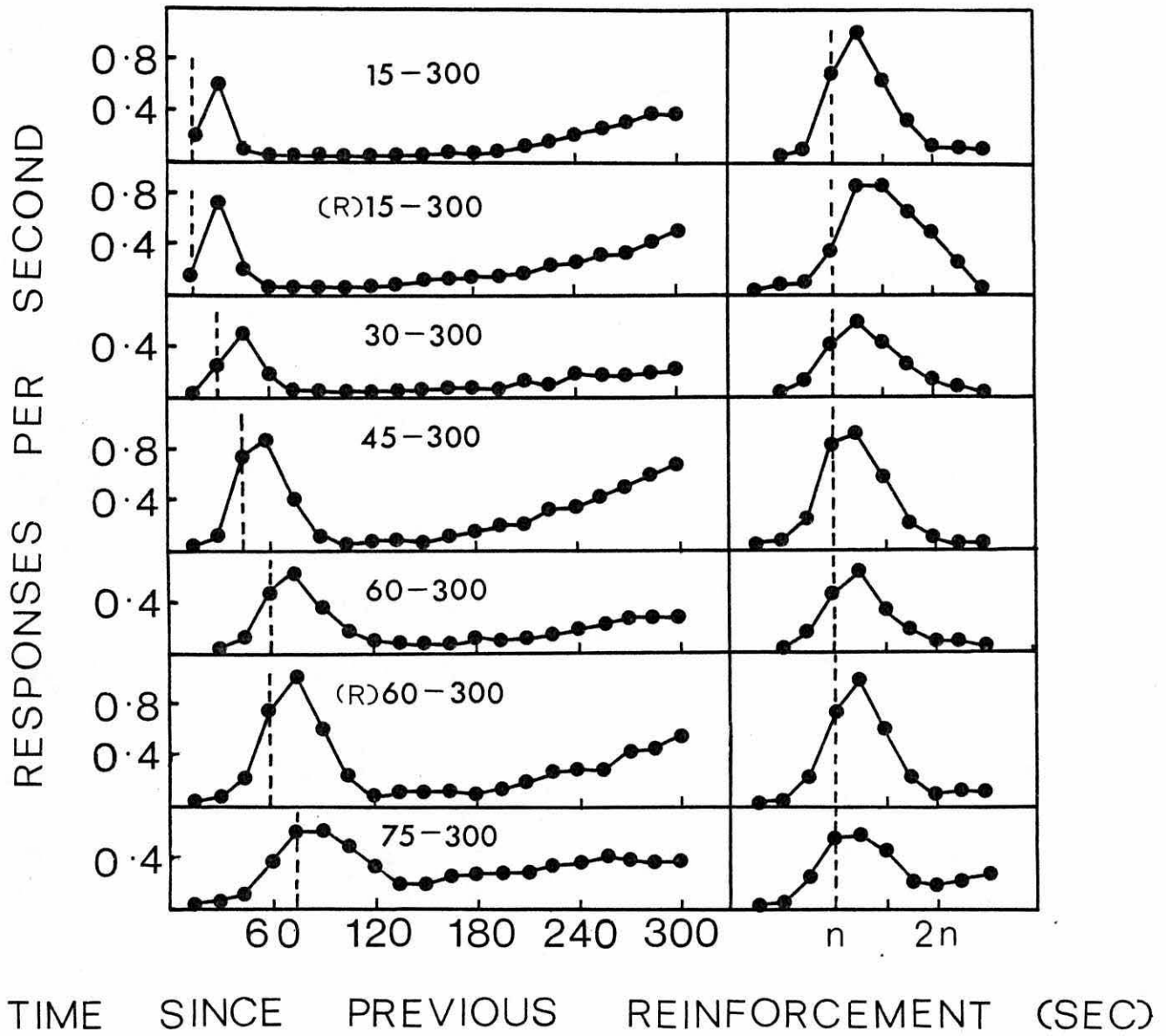
Figure 30.   Experiment 5 :

The local rates of responding for Animal

R34 across the long interval of the mixed

FI (left panel) and the local rate of

responding of the early region of the

long interval plotted on a horizontal

scale, which was proportional to the

duration of the short interval, for each

condition.   (R) shows a redetermination

condition.

R 34

RESPONSES PER SECOND

TIME SINCE PREVIOUS REINFORCEMENT (SEC)

Figure 31. Experiment 5 :

The local rates of responding for Animal
R35 across the long interval of the mixed
FI (left panel) and the local rate of
responding of the early region of the
long interval plotted on a horizontal
scale, which was proportional to the
duration of the short interval, for each
condition.   (R) shows a redetermination
condition.

Figure 32.   Experiment 5 :

The local rates of responding for Animal
R36 across the long interval of the mixed
FI (left panel) and the local rate of
responding of the early region of the
long interval plotted on a horizontal
scale, which was proportional to the
duration of the short interval, for each
condition.   (R) shows a redetermination
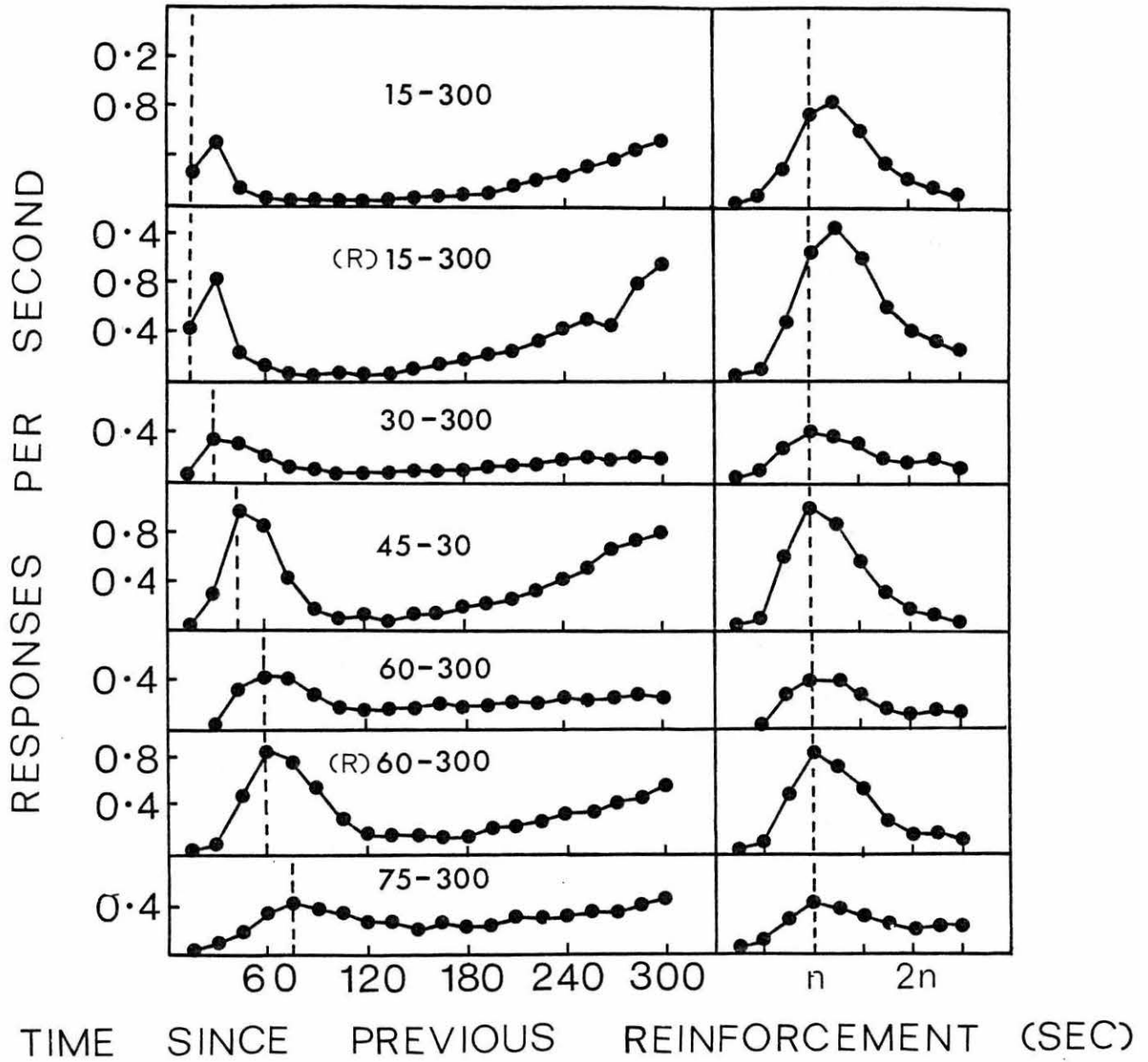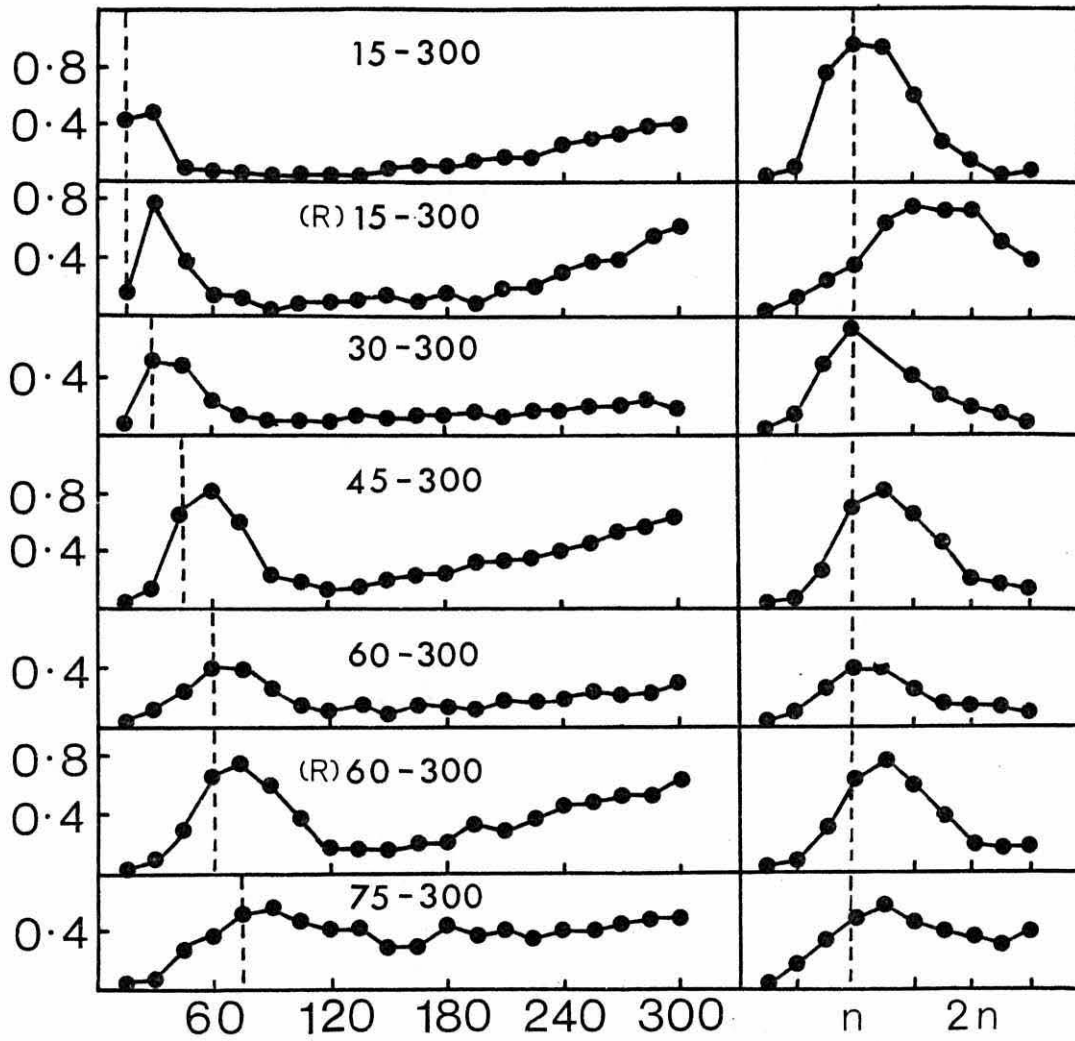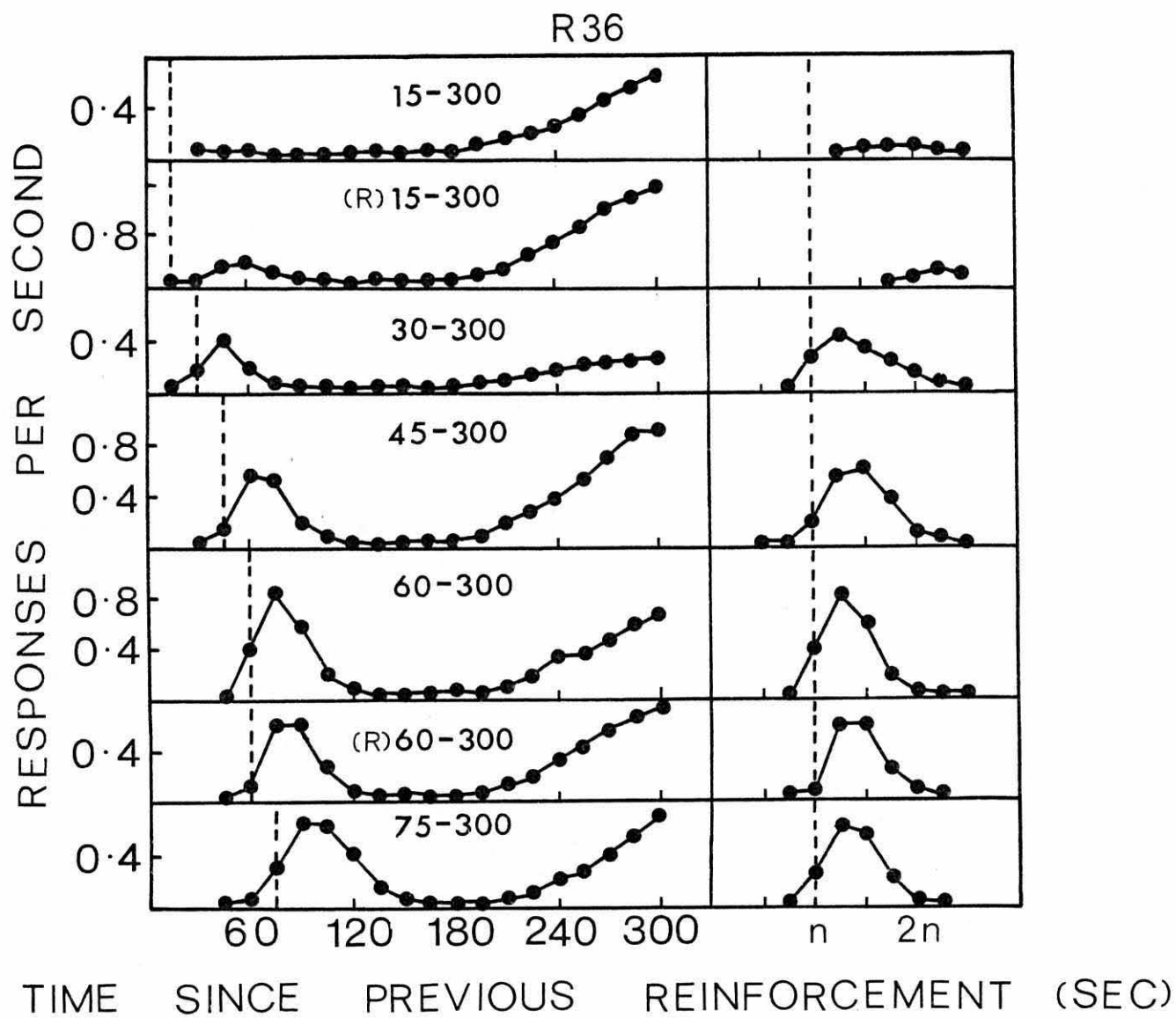condition.

R 36

RESPONSES PER SECOND

TIME SINCE PREVIOUS REINFORCEMENT (SEC)

proportional to the duration of the short interval. It may also be deduced that, to a first approximation, the standard deviation of the distribution was directly proportional to the duration of the small interval, since the shape of the curves is very similar when plotted on this proportional scale.

Figure 30 shows the performance of Animal R34 in the same terms as Figure 29. The performance of this animal can be seen to have been essentially the same as that of Animal R33. It is interesting to note that the peaks of the distributions, seen in the right-hand panel, do not seem to have been displaced to the right of the end of the short interval, except for the mixed FI 15 - FI 300 condition. It may also be seen that the reduction in the local rate of responding in the middle of the long interval on the mixed FI 75 - FI 300 condition is relatively less than that which occurs on the other conditions. This latter finding is consistent with the results of the last experiment where it was shown that a relatively large ratio between the two intervals making up the mixed FI schedule, must exist before this reduction in rate would occur.

Figure 31 shows the performance of Animal R35 ; again it can be seen to have been similar to the other two animals. The performance of Animal R36 is shown in Figure 32 ; here again the pattern of local rates was very similar, though the peak of the

distribution seems to have been rather more displaced from the end of the short interval than the other animals. The other major difference between this animal and the other three was that the inverted U-shaped distribution failed to develop on the mixed FI 15 - FI 300 condition, this was a consistent finding since it can be seen that when this condition was redetermined the same pattern of responding occurred.

The final figure in this experiment, Figure 33, shows some typical sections of cumulative records taken from each animal on the mixed FI 60 - FI 300 schedule condition. It can be seen that they are essentially the same as the cumulative records presented in Experiment III, being characterized by a break in responding in the middle of the long interval.

The results of this experiment would seem to suggest that the peak of the inverted U-shaped distribution depends upon the duration of the short interval. It cannot, however, be deduced from these results what the exact relationship is between the peak and the short interval, owing to the comparatively small range of short intervals used. There are at least two possible relationships between these two variables, either the relationship is linear or it is a power function. There would seem to be a certain degree of evidence in the literature to suggest that the relationship is in fact a power function. Killeen (1975), using data of his own and

Figure 33.   Experiment 5 :

Sections of typical cumulative record

for each animal taken from the mixed

FI 60 - FI 300-sec schedule condition.
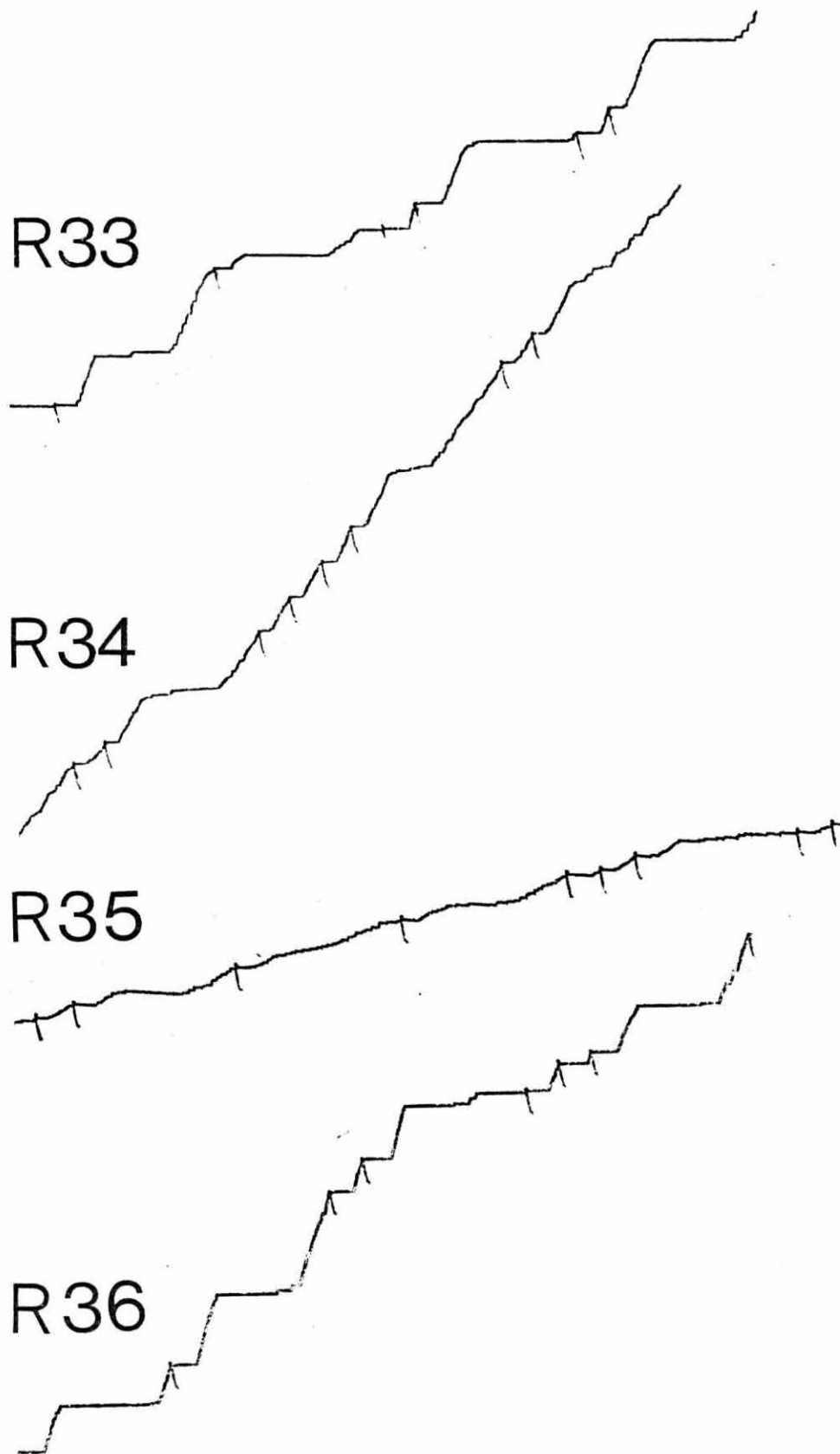
data from Catania and Reynolds (1968) and Dukich and Lee (1973)
fitted normal curves to the local rate function of various FI
schedules. He found that the relationship between the FI value
and the peak of the normal curve was described by a power function.
Though there was a difference in the exponents of the power functions
fitting the data of Catania and Reynolds' pigeons and Dukich and
Lees' rats, the pigeons shewing an exponent of just less than 1
and the rats having an exponent of just above 1. Similar results
were also reported by Lowe and Harzem (1977).

General Discussion.

Taking the results of these experiments as a whole, it
has been shown that a bell-shaped distribution of local rates of
responding will occur on a mixed FI schedule, provided that the
ratio between the two intervals making up the mixed FI is
sufficiently large enough. The result would also seem to point to
this bell-shaped distribution being a gradient of temporal
generalization, since it was shown in Experiment III that the
factor determining the acceleration and deceleration of the local
rate of responding was time, and not response number. The peak
of the distribution is correlated with the length of the short
interval, which means that the peak is also correlated with the

temporal position of reinforcement. Similarly, the spread of the
curve is determined by the duration of the small interval, which
suggests that the curve is due to a Weber-type timing process such
as that proposed by Gibbon (1977).

The implications of these findings for the interpretation
of the pattern of responding produced on the FI schedule could be
quite significant. For example, it is difficult to see how these
results could be explained in terms of Dews (1962) and Morse (1966)
theories, which explain FI performance in terms of the relative
delays between a response made at the beginning and the end of an
interval and reinforcement. Similarly, those theories that would
only allow for temporal disrcrimination in one part of the fixed
interval, either the postreinforcement pause or the run time, such
as those of Schneider (1969) and Shull (1979), would be incompatible
with these findings. Probably the interpretation of FI performance
that would best fit these findings would be that of Catania and
Reynolds (1968), who have suggested that the pattern of responding
on FI may be interpreted in terms of the left-hand side of a gradient
of temporal generalization.

So far in this thesis, all the mixed FI schedules that
have been looked at have been evenly probable two-valued schedules.
However, the majority of irregular temporally defined schedules of
reinforcement have more than two intervals, with the result that the

probability of reinforcement at the end of the short interval is usually far less than 0.5. The next chapter will consider the patterns of behaviour produced by two-valued mixed FI schedules in which the relative frequency of the two intervals is varied.

CHAPTER 7

SOME DETERMINANTS OF PERFORMANCE
ON UNEVENLY PROBABLE
TWO-VALUED MIXED FIXED-INTERVAL SCHEDULES

The results of the experiments reported in the previous two chapters would seem to suggest that the postreinforcement pause, on an evenly probable two-valued mixed FI schedule, is mainly determined by the duration of the short interval of that schedule. However, as was pointed out at the end of the last chapter the majority of irregular temporally defined schedules are made up of

far more than two intervals and hence the probability of the shortest interval is considerably less than 0.5.

Very little work has been done on the effect of varying the probability of the short interval in a simple irregularly temporally defined schedule. Millenson (1959) varied the probability of different cycle lengths defined according to Schoenfeld, Cumming and Hearst's (1956) t-system. One condition in this study was equivalent to a mixed FI schedule. Though he did not give any quantitive data for either the postreinforcement pause or the local rate of responding, he did present some cumulative records for the mixed cycle length of 30-sec and 120-sec, with a probability of the 30-sec cycle at 0.6 and 0.4. It can be seen from these cumulative records that the subjects seemed to pause after reinforcement for a substantial part of the interval. There was a slight difference in the pattern of responding after the pause on the two different probabilities of the 30-sec interval; the pigeons responded at a seemingly constant rate when the probability of 30-sec cycle was 0.4, but when this probability was increased to 0.6, the running rate appeared to be somewhat more erratic.

Catania and Reynolds (1968) also looked at two different probabilities of short intervals in a two valued mixed FI schedule. They found that on mixed FI30 - FI240-sec the local rate of

responding at the end of the 30-sec interval was far less when the probability of reinforcement was 0.05 than when it was 0.50. As with Millenson (1959), they did not present any data for postreinforcement pause. They did, however, give some cumulative records from which it can be seen that the mixed FI30 - FI240-sec schedule, with the probability of the 30-sec interval of 0.05, has a substantially reduced postreinforcement pause, from that which occurred in the FI 240-sec condition.

The purpose of the experiments reported in this chapter is to determine the effect of varying the relative probabilities of the two intervals in a mixed FI schedule upon the performance produced by that schedule.

Experiment VI

Method.

Subjects.

Four, naive, hooded, male rats, approximately 12 weeks' old at the start of the experiment, served as subjects. They were individually housed and maintained at 80% of their free feeding weight throughout the experiment. Water was freely available in their home cages. One of the animals died early in the experiment, so no data is presented for it.

Table 7.   Experiment 6 :

The conditions on which the animals
were trained, given in the order in
which they were trained.   The number
of sessions of training, the mean
postreinforcement pause (PRP) and the
standard deviation of the pauses (SD)
are also given for each animal on
each condition.

Table 7

Animal	Schedule	Pr FI30	Number of Sessions	Postreinforcement Pause	
				Mean	SD
R18	Mixed FI30-FI60 sec	0.50	58	16.65 sec	6.88 sec
	FI30 sec	1.00	37	22.52 sec	6.95 sec
	Mixed FI30-FI60 sec	0.70	32	22.12 sec	11.42 sec
	Mixed FI30-FI60 sec	0.30	41	23.49 sec	8.70 sec
	FI60 sec	0.00	32	43.41 sec	12.94 sec
	Mixed FI30-FI60 sec	0.90	36	21.26 sec	8.29 sec
	Mixed FI30-FI60 sec	0.10	25	34.84 sec	15.50 sec
	Mixed FI30-FI60 sec	0.70	28	25.60 sec	6.33 sec
	Mixed FI30-FI60 sec	0.10	25	38.27 sec	11.66 sec
R19	Mixed FI30-FI60 sec	0.50	60	15.34 sec	5.97 sec
	FI30 sec	1.00	38	18.33 sec	6.57 sec
	Mixed FI30-FI60 sec	0.70	31	22.12 sec	5.59 sec
	Mixed FI30-FI60 sec	0.30	41	22.65 sec	8.61 sec
	FI60 sec	0.00	32	34.25 sec	10.99 sec
	Mixed FI30-FI60 sec	0.90	38	19.50 sec	6.97 sec
	Mixed FI30-FI60 sec	0.10	25	29.08 sec	13.58 sec
	Mixed FI30-FI60 sec	0.70	28	20.53 sec	6.08 sec
	Mixed FI30-FI60 sec	0.10	26	29.25 sec	11.44 sec
R20	Mixed FI30-FI60 sec	0.50	56	12.51 sec	8.91 sec
	FI30 sec	1.00	37	12.98 sec	9.82 sec
	Mixed FI30-FI60 sec	0.70	30	9.59 sec	8.35 sec
	Mixed FI30-FI60 sec	0.30	40	14.37 sec	12.00 sec
	FI60 sec	0.00	31	15.03 sec	15.14 sec
	Mixed FI30-FI60 sec	0.90	37	12.87 sec	10.01 sec
	Mixed FI30-FI60 sec	0.10	26	17.60 sec	17.05 sec
	Mixed FI30-FI60 sec	0.70	28	11.87 sec	10.43 sec
	Mixed FI30-FI60 sec	0.10	26	16.41 sec	14.78 sec

Apparatus.

The apparatus was described in chapter 4 on experimental method. The operant chambers used in this experiment were four Lehigh Valley models, 42 - 25.

Procedure.

Lever-pressing responses were shaped in the first session, the animals were then allowed to obtain 60 contingent reinforcements on a CRF schedule. After this preliminary training the animals were trained on several schedules, two of which were FI 60 and FI 30, the remainder were mixed FI 30 - FI 60, in which the probability of the intervals was varied between 0.9 and 0.1. The details of order and the number of sessions of training for each schedule are given in Table 7. Two redetermination conditions were taken and training in all conditions was continued until the animals performance was considered to be stable.

Results and Discussion.

Figure 34 shows the relationship between the postreinforcement pause and the probability of the 30-sec interval in the mixed FI. The unconnected points represent the redetermination conditions. The general trend seems to be a reduction in the postreinforcement pause, as the probability of the 30-sec interval increases up to 0.5. This was followed by a levelling off in the duration of the pause for probabilities of the 30-sec interval greater than 0.5. This

Figure 34.   Experiment 6 :
The postreinforcement pause on all
conditions, for all animals, as a
function of the probability of the
30-sec interval.   The unconnected
points represent redetermination
conditions.

R18

R19

R20

PAUSE (SEC)

POSTREINFORCEMENT

PROBABILITY OF THE
30sec INTERVAL
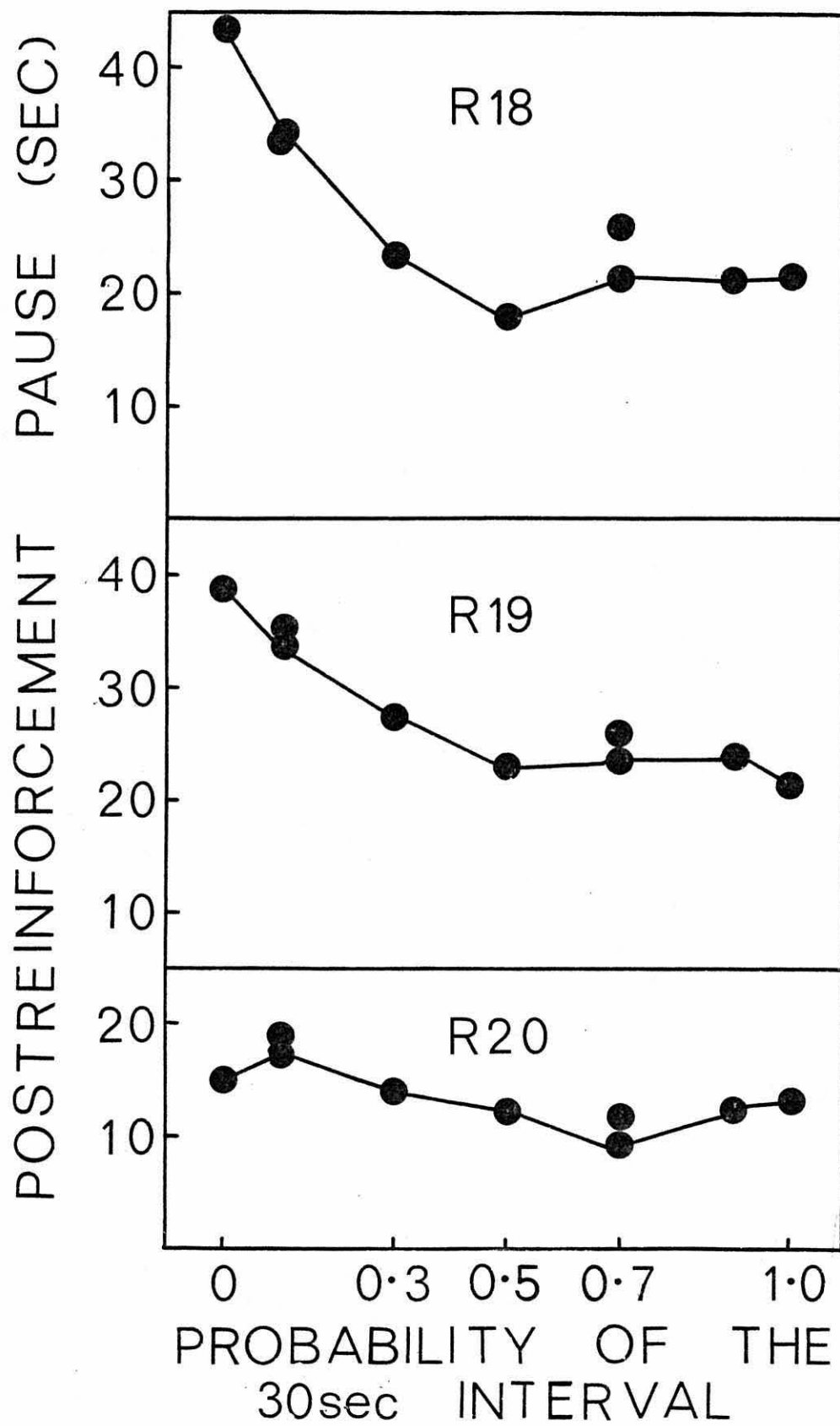
result being consistent with the findings reported in the last
two chapters in which it was shown that the postreinforcement pause
was mainly determined by the short interval.

Figure 35 shows the local rate of responding for Animal
R18 on all the conditions. It can be seen that its performance
on the mixed FI conditions, in which the probability of the 30-sec
interval was 0.5 or greater, is characterised by a gradual
acceleration in the rate of responding until the 30-sec point, very
similar to the performance in the FI 30-sec condition ; followed
by a constant local rate of responding until the 60-sec point.
In the two conditions in which the probability of the 30-sec interval
was less than 0.5 a different pattern of behaviour occurred, the
local rate of responding continued to increase until the 60-sec
point.

This pattern of behaviour also seemed to occur with
Animal R19, Figure 36. Though this animal differs in that there
is a slight decline in the local rate of responding just after the
30-sec point for the two conditions where the probability of the
30-sec interval is above 0.5 in the mixed FI. When the probability
drops to 0.5, the local rate of responding remains more or less
constant after the 30-sec point. For the two conditions in which
the probability of the 30-sec interval is less than 0.5 there is
again a continuation in the increase in local rate of responding.

Figure 35.   Experiment 6 :

The local rate of responding on all

conditions for Animal R18.   The

conditions marked (R) are

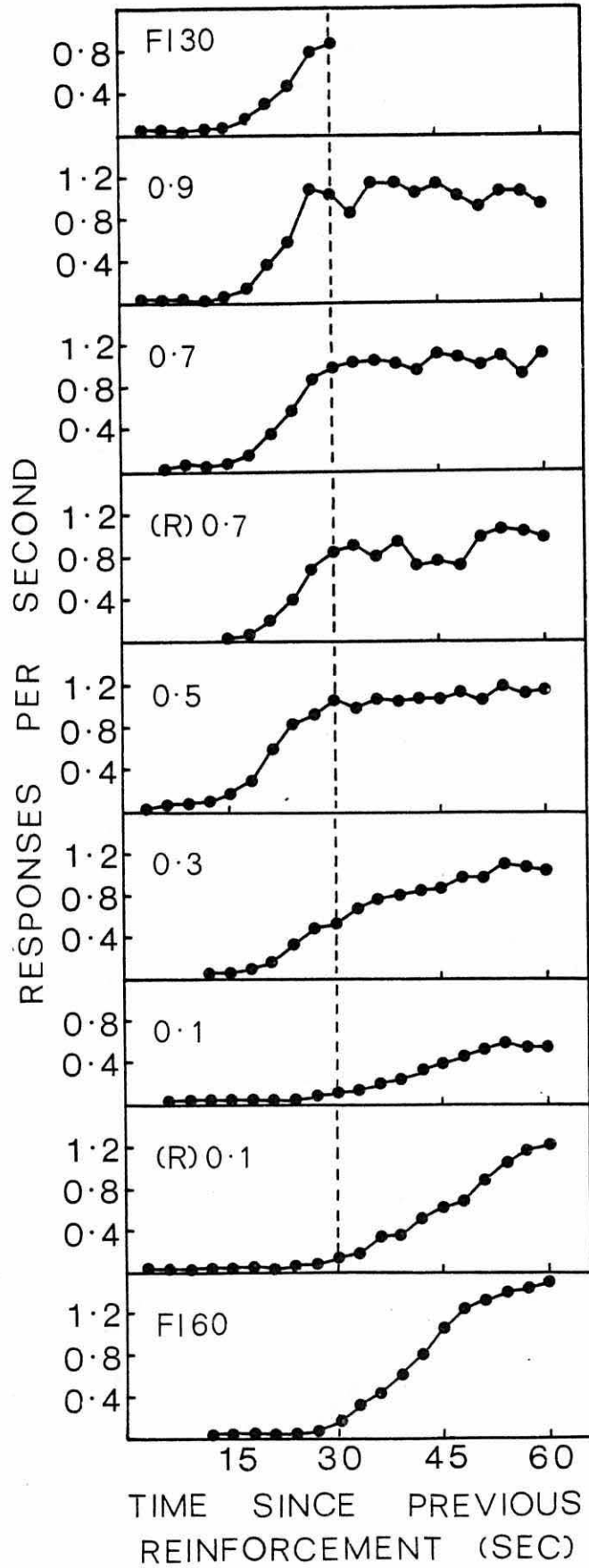redetermination conditions.

Figure 36.   Experiment 6 :

The local rate of responding on all

conditions for Animal R19.   The

conditions marked (R) are
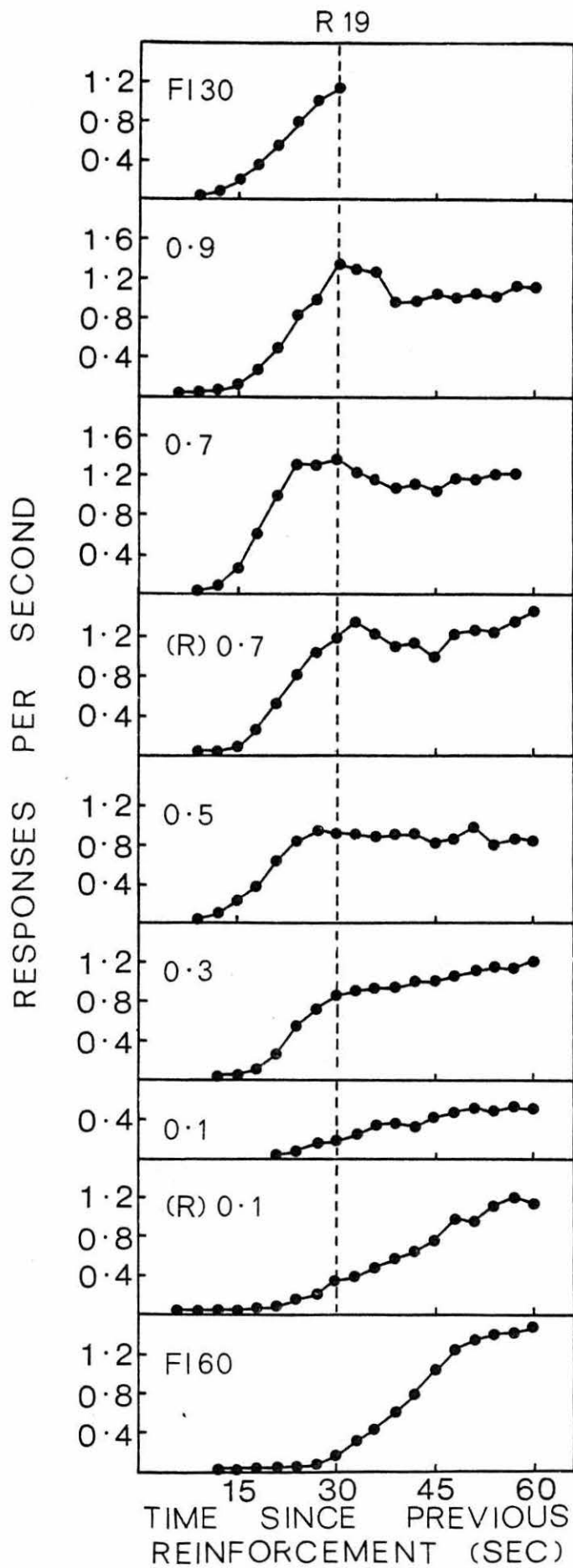
redetermination conditions.

Figure 37. Experiment 6 :

The local rate of responding on all

conditions for Animal R20. The

conditions marked (R) are

redetermination conditions.
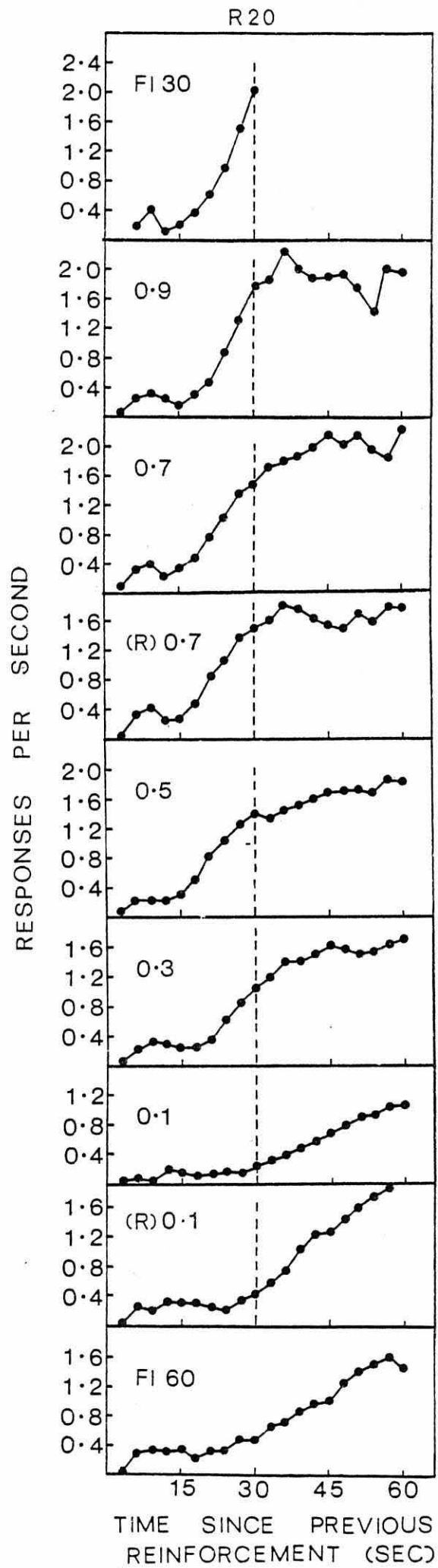
The performance of Animal R20 is shown in Figure 37.
Generally this animal's pattern of responding is similar to the
other two animals, though it does seem to produce somewhat atypical
behaviour for an animal responding on an interval schedule.

From both the data presented in the form of the local
rates of responding and in terms of the postreinforcement pause,
it can be deduced that, as the probability of the 30-sec interval
is reduced below 0.5, its influence upon the pattern of responding
also diminishes.   The general finding for local rate of responding
is that, when the probability of the 30-sec interval is greater
or equal to 0.5, the local rate of responding reaches its maximum
at about the 30-sec point, and then remains approximately constant
until the terminal reinforcement at the 60-sec point.   If the
probability of the 30-sec interval was less than 0.5, then the
maximum local rate of responding occurred towards the end of the
60-sec interval.   With the data for postreinforcement pause it was
found that when the probability of the 30-sec interval was 0.5 or
above, there was no systematic change in its duration ;   but when
the probability of the 30-sec interval falls below 0.5 there was
a systematic increase in the pause duration.

An explanation of these findings may lie in some
observations made by Catania and Reynolds (1968).   They found that
there was a positive relationship between the local rate of
responding and the local rate of reinforcement.   It was demonstrated
in the Chapter 6 of this thesis, as well as being suggested by

Catania and Reynolds, that the effect of having a probability of reinforcement at a discrete point in time upon the local rates of responding about that point, depends upon the temporal distance between the point at which reinforcement may occur and the time at which behaviour occurs. As time to reinforcement gets less the local rate of responding increases. What may happen is as follows. As the local rate of reinforcement is reduced by means of reducing the probability of reinforcement at the end of the 30-sec interval, the local rate of responding about that point will also be reduced. This reduction in rate may also be construed as a reduction in the probability of the animal making a response in a unit time. Since this probability of making a response will be reduced early in the interval, postreinforcement pause is likely to increase. This explanation is consistent with the findings of Herrnstein (1970) that the rate of responding is functionally related to the rate of reinforcement delivery. It is also consistent with the finding of Dews (1970), that the rate of responding at a particular proportional point during a fixed interval is related to the terminal rate of responding in that interval. Thus, from this it would follow that, if the rate of responding in an interval was reduced by decreasing the probability of reinforcement at the end of the interval, this decrease in rate would effect the entire interval proportionally and would increase the pause.

A second experiment was performed, in which the relative probabilities of the two intervals occurring in a mixed FI schedule were varied. In this experiment the ratio between the two intervals was increased so that the effect of a particular probability of reinforcement at the end of the short interval, upon early responding, could be seen in relative isolation from any effects from the probability of reinforcement at the end of the long interval.

Experiment VII

Method.

Subjects.

Four, naive, hooded male rats, approximately 12 weeks' old at the start of the experiment served as subjects. They were individually housed and maintained at 80% of their free feeding weight throughout the experiment. Water was freely available in their home cages.

Apparatus.

The apparatus was described in Chapter 4 on experimental method. The operant chambers used in this experiment were four Lehigh Valley model RTC - 028.

Table 8.   Experiment 7 :

The conditions on which the animals
were trained, given in the order in
which they were trained.   The number
of sessions of training, the mean
postreinforcement pause (PRP) and the
standard deviation of the pauses (SD)
are also given for each animal on
each condition.

Table 8

Animal	Schedule	Pr FI30	Number of Sessions	Postreinforcement Pause	
				Mean	SD
R25	FI30 sec	1.00	30	33.80 sec	9.60 sec
	Mixed FI30-FI120 sec	0.50	26	30.56 sec	8.25 sec
	Mixed FI30-FI120 sec	0.70	25	25.33 sec	6.40 sec
	FI120 sec	0.00	25	96.66 sec	30.21 sec
	Mixed FI30-FI120 sec	0.30	29	28.08 sec	14.92 sec
	FI30 sec	1.00	25	30.76 sec	4.78 sec
	FI120 sec	0.00	23	85.71 sec	32.05 sec
R26	FI30 sec	1.00	30	16.71 sec	9.25 sec
	Mixed FI30-FI120 sec	0.50	26	20.49 sec	7.00 sec
	Mixed FI30-FI120 sec	0.70	25	21.95 sec	8.08 sec
	FI120 sec	0.00	25	30.77 sec	26.60 sec
	Mixed FI30-FI120 sec	0.30	29	15.76 sec	7.05 sec
	FI30 sec	1.00	25	11.14 sec	6.97 sec
	FI120 sec	0.00	23	27.87 sec	18.95 sec
R27	FI30 sec	1.00	30	16.67 sec	8.08 sec
	Mixed FI30-FI120 sec	0.50	26	21.21 sec	13.26 sec
	Mixed FI30-FI120 sec	0.70	25	16.48 sec	9.12 sec
	FI120 sec	0.00	25	77.89 sec	37.09 sec
	Mixed FI30-FI120 sec	0.30	29	27.14 sec	20.00 sec
	FI30 sec	1.00	25	18.69 sec	10.74 sec
	FI120 sec	0.00	23	71.58 sec	35.06 sec
R28	FI30 sec	1.00	30	23.41 sec	6.45 sec
	Mixed FI30-FI120 sec	0.50	26	25.08 sec	9.52 sec
	Mixed FI30-FI120 sec	0.70	25	25.73 sec	9.08 sec
	FI120 sec	0.00	25	62.89 sec	28.03 sec
	Mixed FI30-FI120 sec	0.30	29	23.85 sec	12.47 sec
	FI30 sec	1.00	25	23.36 sec	7.82 sec
	FI120 sec	0.00	23	71.15 sec	27.39 sec

Procedure.

Lever-pressing responses were shaped in the first session.
The animals were then allowed to obtain 60 contingent reinforcements
on a CRF schedule. After this preliminary training the animals
were trained on several schedules, two of which were FI 30 and
FI 120, the remainder were mixed FI 30 - FI 120 schedules, in which
the probability of the two intervals varied between 0.7 and 0.3.
Two redetermination conditions were taken and training in all
conditions was continued until the animals were considered to be
stable. The order the animals were trained on in each schedule,
and the number of sessions of training used are given in Table 8.

Results and Discussion.

Figure 38 shows the relationship between the postreinforce-
ment pause and the probability of reinforcement at the end of the
30-sec interval. The unconnected points represent redetermination
conditions. It can be seen that, with the possible exception of
Animal R27, the postreinforcement pause seems to be entirely
determined by the short interval in the mixed FI over the range of
probabilities used in this experiment, since there does not seem to
be any systematic difference between the postreinforcement pause on
the mixed FI schedules and the postreinforcement pause on the
FI 30-sec condition.

Figure 38.   Experiment 7 :

The postreinforcement pause on all

conditions, for all animals, as a

function of the probability of the

30-sec interval.   The unconnected

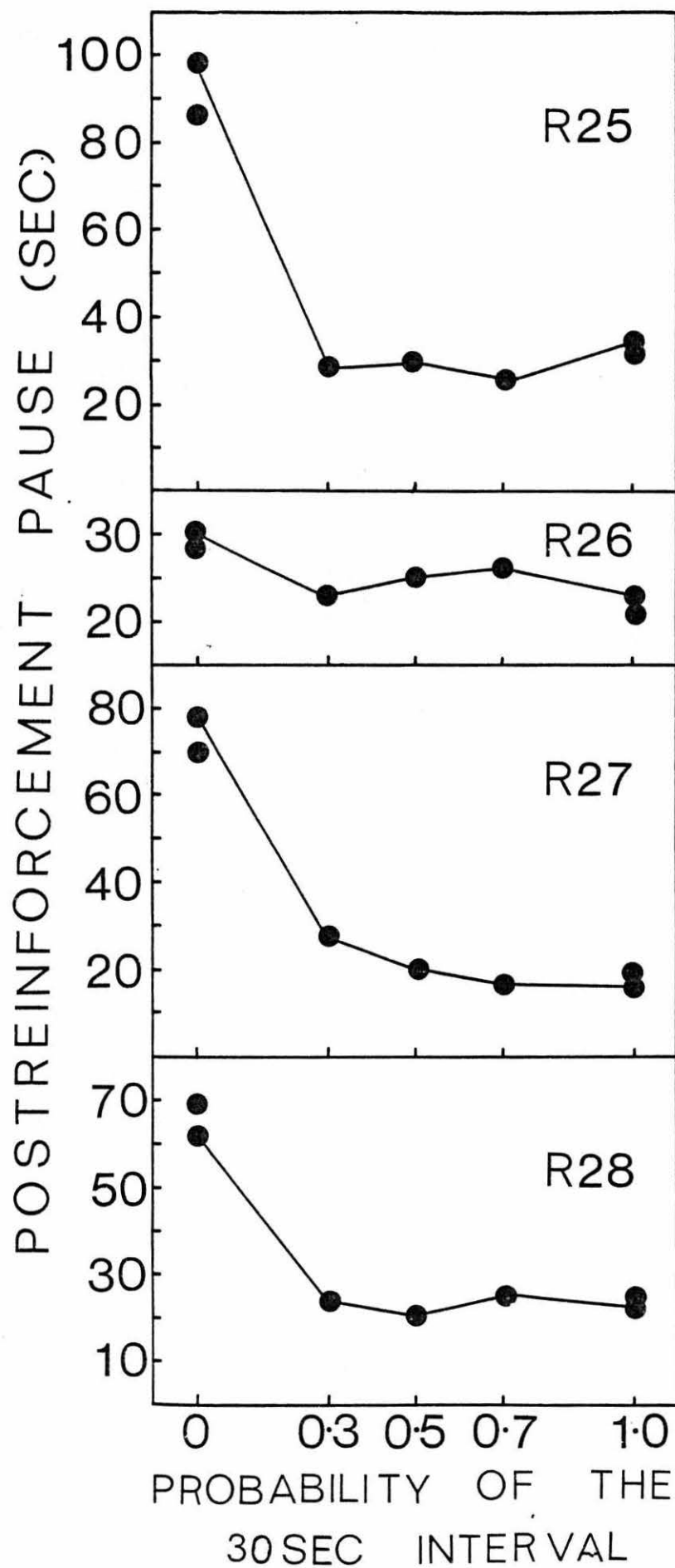points represent redetermination

conditions.

Figure 39 shows the local rate of responding of Animal
R25 on all the conditions.   It can be seen that in the two mixed
FI schedules, in which the probability of the 30-sec interval was
0.5 or 0.7, there was an inverted U-shaped distribution of local
rates of responding around the point just to the right of the
30-sec mark.   This distribution being similar to those reported
in the last chapter.   It is reasonable to assume that this high
rate of responding early in the interval was maintained by the
probability of reinforcement at the end of the 30-sec interval,
since when this probability was reduced to 0.3 or eliminated
altogether, as in the FI 120-sec condition, the high rate of
responding early in the interval diminished.   Similar local rates
of responding may be observed for the other three animals.
Though it should be pointed out that the local rates of responding
maintained by the 0.3 probability of reinforcement at the end of
the 30-sec interval for Animal R28 (Figure 42) is higher than it
is in the same part of this interval in this condition for either
Animal R25 (Figure 39), Animal R27 (Figure 41) or Animal R26
(Figure 40), it also produces a higher local rate of responding
at this point in the interval on this condition than either
Animals R25 or R27.   However, Animal R26 also differs from
Animal R28 in that the local rate of responding does not decline
in mid-interval.   This would indicate that the rate of responding
maintained by a particular probability of a reinforcement is
subject to some individual differences, though the overall

Figure 39.   Experiment 7 :

The local rate of responding on all

conditions for Animal R25.   The

conditions marked (R) are

redetermination conditions.

Figure 40.   Experiment 7 :

The local rate of responding on all

conditions for Animal R26.   The

conditions marked (R) are

redetermination conditions.

R26
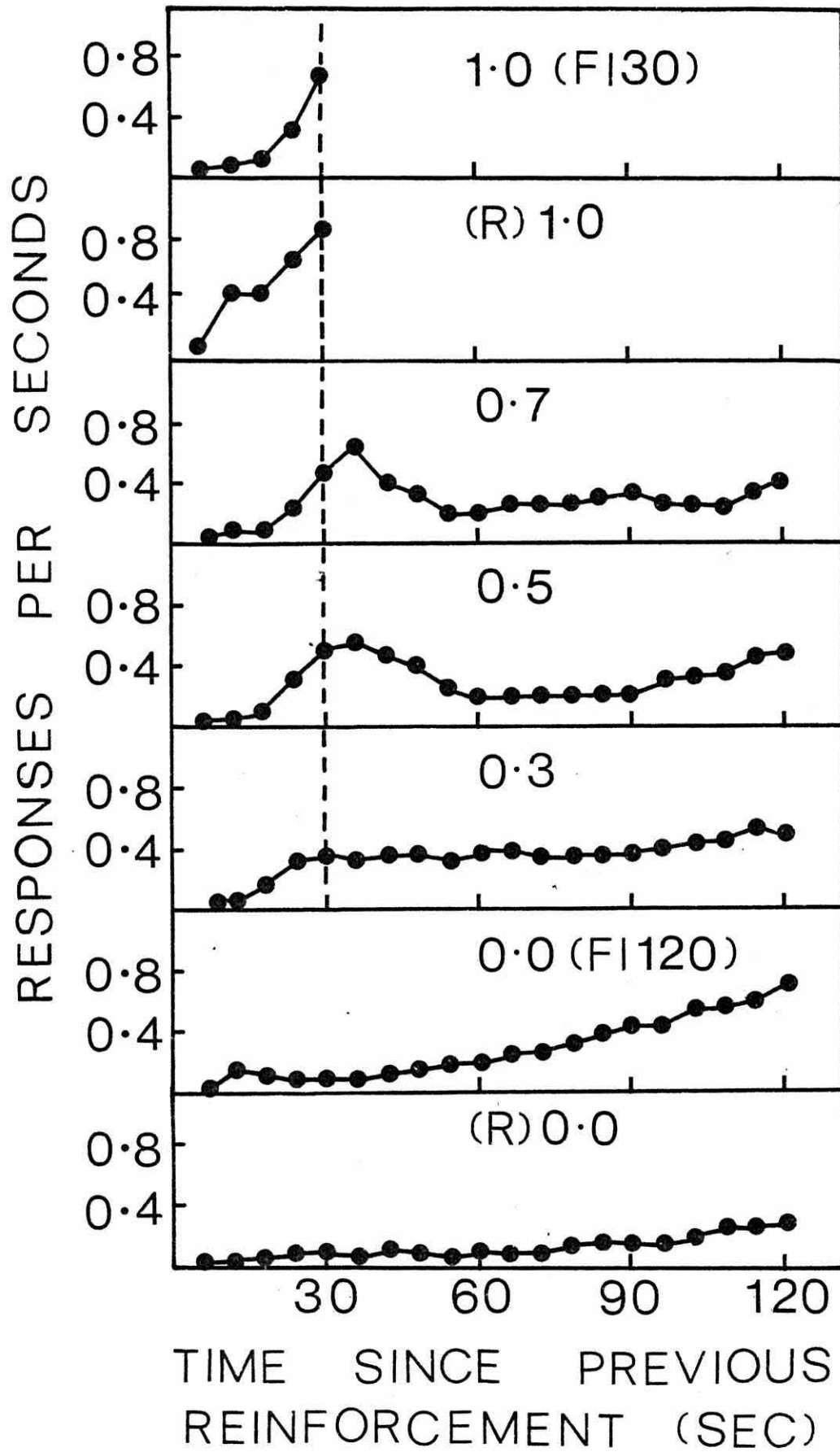
Figure 41.   Experiment 7 :

The local rate of responding on all

conditions for Animal R27.   The

conditions marked (R) are

redetermination conditions.
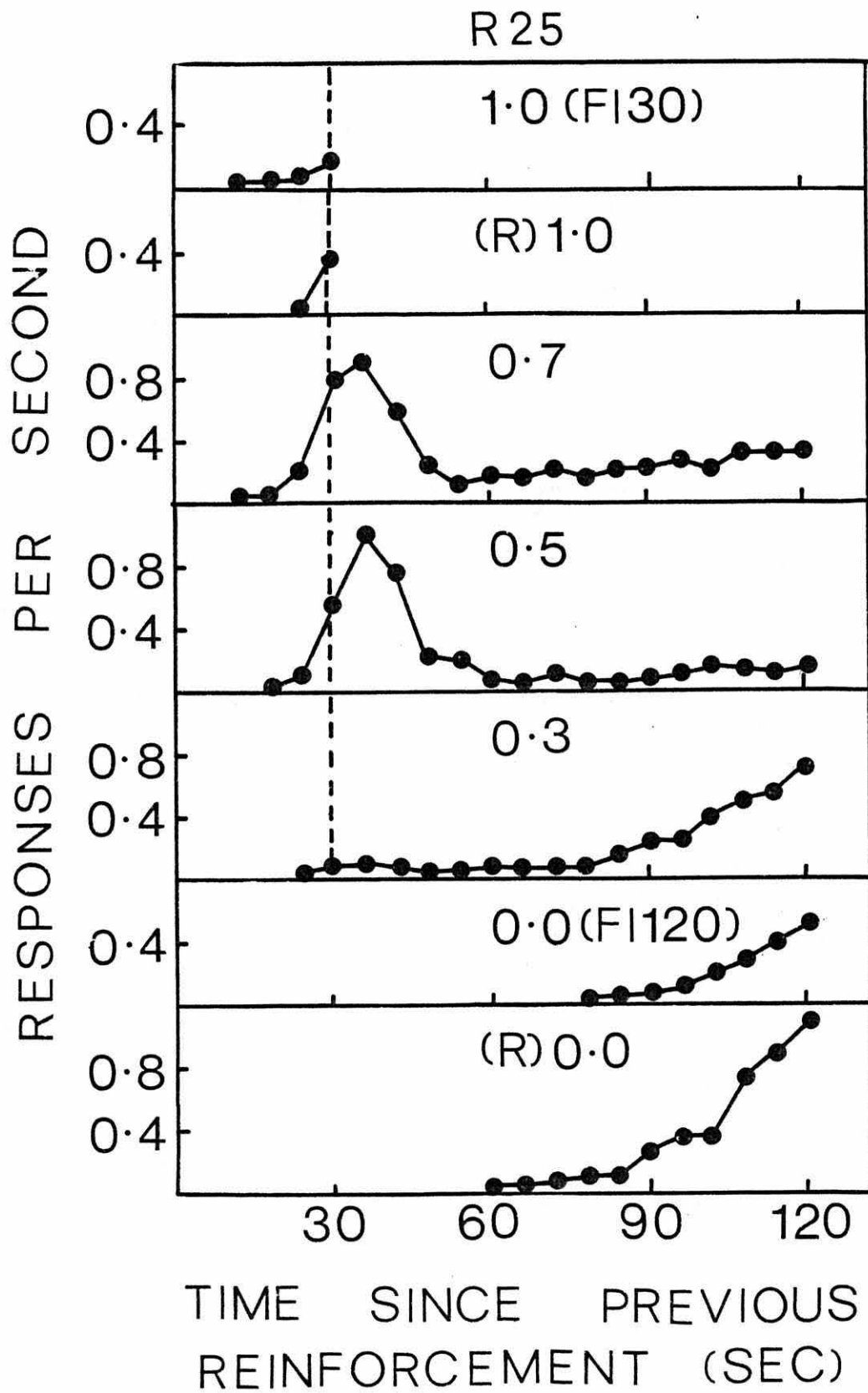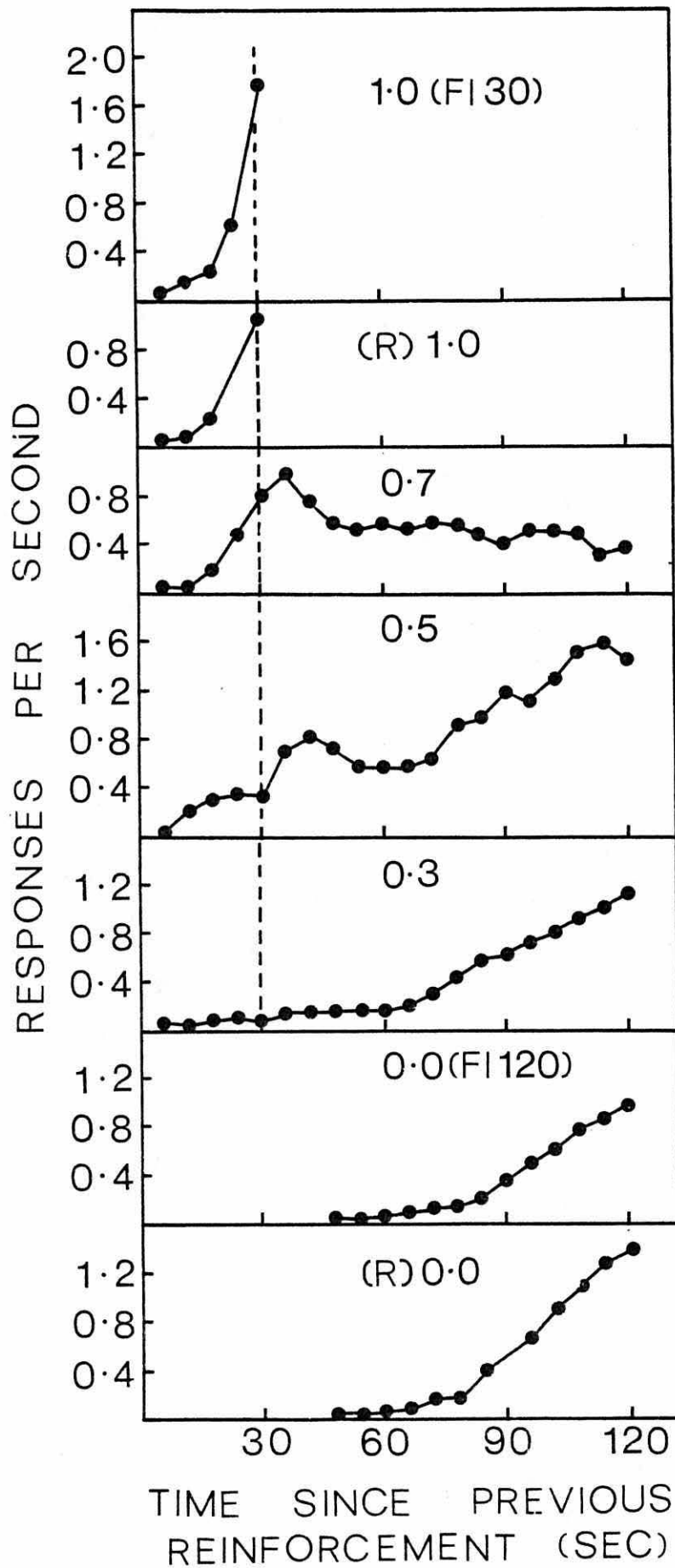
Figure 42.   Experiment 7 :

The local rate of responding on all

conditions for Animal R28.   The

conditions marked (R) are

redetermination conditions.
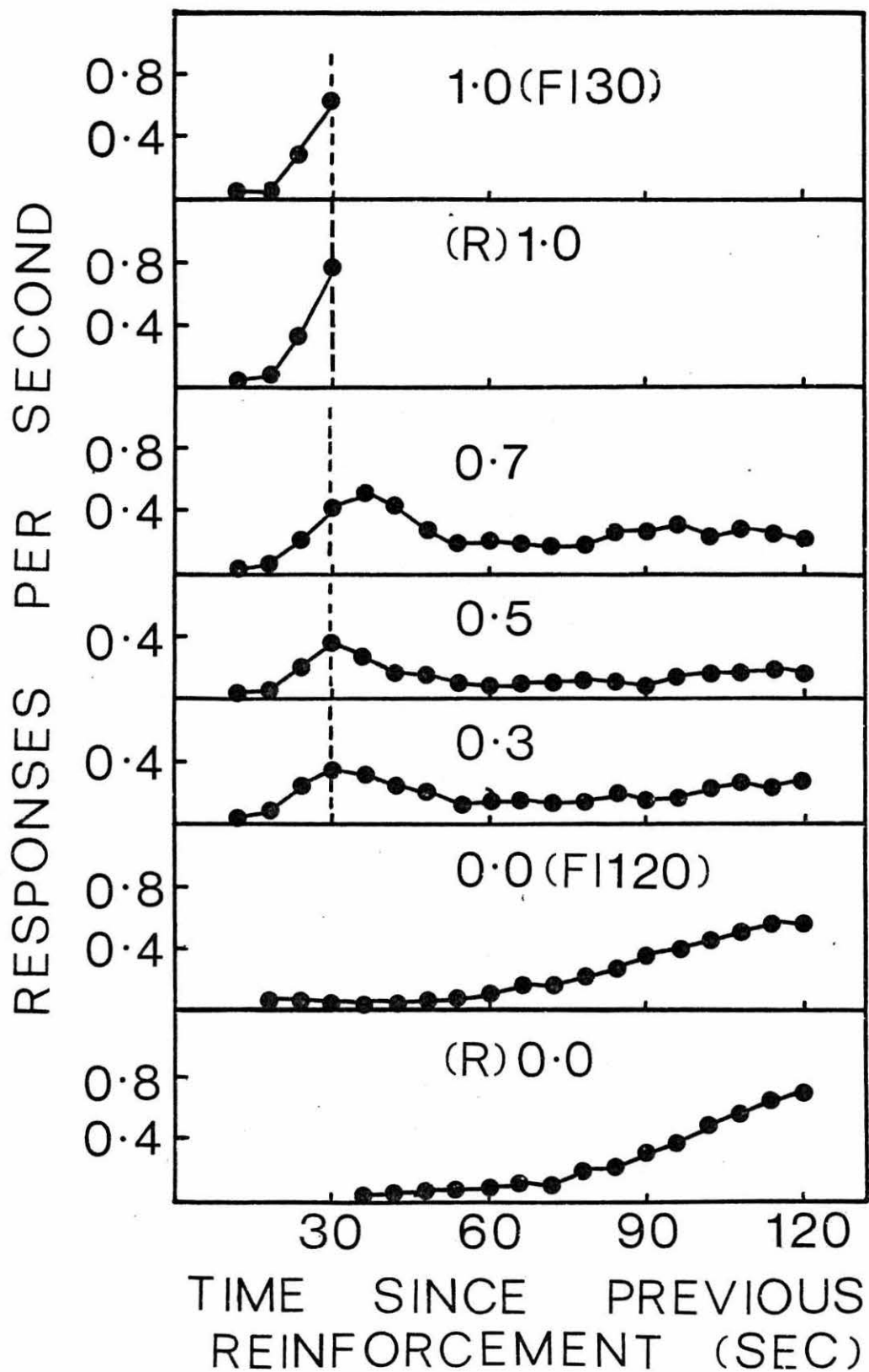
conclusion can be drawn from these results that a sufficient reduction in the probability of reinforcement reduces the local rate of responding maintained by that probability of reinforcement.

It would be difficult, as yet, to apply these findings to an explanation of VI responding since it has been reported that the postreinforcement pause on VI schedules can exceed the duration of the minimum interval. For example, Harzem, Lowe and Priddle-Higson (1978) reported that in one VI they used, in which the shortest interval was 4 seconds, the mean postreinforcement pause was about 5-sec. On a second VI schedule, used by them, there was an interval on which the animal was reinforced for its first response after reinforcement. They reported that on this schedule the mean pause was about 9-sec. The next experiment reported in this chapter was designed to investigate the effect upon behaviour of having an immediate opportunity for reinforcement, at various probability values.

Experiment VIII

Method

Subjects.

Four, hooded, male rats approximately 20 weeks' old at
the start of the experiment, served as subjects. They had had
previous experience of an FI 120-sec schedule. They were
individually housed and maintained at 80% of their free-feeding
weight throughout the experiment. Water was freely available
in the home cages.

Apparatus.

The apparatus was described in chapter 4 on experimental
method. The operant chambers used in this experiment were four
Lehigh Valley model RTC-028.

Procedure.

The animals, having already had a preliminary training,
were trained on several schedules, two of which were FI 60-sec and
CRF, the others were mixed CRF - FI 60 in which the probability
of the CRF contingency was varied between 0.5 and 0.99. The
order and number of sessions used for each condition are given in
Table 9.

Table 9.   Experiment 8 :

The conditions on which the animals
were trained, given in the order in
which they were trained.   The number
of sessions of training, the mean
postreinforcement pause (PRP) and the
standard deviation of the pauses (SD)
are also given for each animal on
each condition.

Table 9

Animal	Schedule	Pr FI60	Number of Sessions	Postreinforcement Pause	
				Mean	SD
R21	FI60 sec	1.00	35	47.78 sec	8.98 sec
	Mixed FI60-CRF	0.50	40	7.51 sec	3.39 sec
	Mixed FI60-CRF	0.90	32	24.93 sec	16.82 sec
	CRF	0.00	25	5.75 sec	2.49 sec
	Mixed FI60-CRF	0.99	25	42.90 sec	10.90 sec
	Mixed FI60-CRF	0.70	25	20.04 sec	14.81 sec
	Mixed FI60-CRF	0.50	23	8.94 sec	4.59 sec
	FI60 sec	1.00	28	46.46 sec	13.45 sec
R22	FI60 sec	1.00	33	53.85 sec	23.14 sec
	Mixed FI60-CRF	0.50	38	5.50 sec	1.91 sec
	Mixed FI60-CRF	0.90	25	54.86 sec	30.66 sec
	CRF	0.00	25	4.94 sec	2.21 sec
	Mixed FI60-CRF	0.99	25	45.60 sec	17.45 sec
	Mixed FI60-CRF	0.70	26	7.22 sec	4.06 sec
	Mixed FI60-CRF	0.50	25	5.35 sec	2.51 sec
	FI60 sec	1.00	27	47.51 sec	14.91 sec
R23	FI60 sec	1.00	29	57.77 sec	19.02 sec
	Mixed FI60-CRF	0.50	40	3.30 sec	4.63 sec
	Mixed FI60-CRF	0.90	27	4.22 sec	4.78 sec
	CRF	0.00	25	6.19 sec	3.30 sec
	Mixed FI60-CRF	0.99	25	60.43 sec	20.84 sec
	Mixed FI60-CRF	0.70	25	3.15 sec	2.28 sec
	Mixed FI60-CRF	0.50	23	5.34 sec	2.79 sec
	FI60 sec	1.00	24	54.31 sec	20.91 sec
R24	FI60 sec	1.00	32	53.97 sec	10.04 sec
	Mixed FI60-CRF	0.50	37	11.27 sec	10.55 sec
	Mixed FI60-CRF	0.90	28	23.71 sec	19.43 sec
	CRF	0.00	25	8.96 sec	3.29 sec
	Mixed FI60-CRF	0.99	23	60.45 sec	16.86 sec
	Mixed FI60-CRF	0.70	24	20.50 sec	19.56 sec
	Mixed FI60-CRF	0.50	25	9.63 sec	8.88 sec
	FI60 sec	1.00	27	57.51 sec	13.87 sec

Results and Discussion.

Figure 43 shows the relationship between the post-reinforcement pause and the probability of the CRF contingency, for each animal. The unconnected points represent the redetermination conditions. In all cases the postreinforcement pause on the condition in which the probability of the CRF contingency was 0.5, was virtually the same as the postreinforcement pause on the CRF condition. This result being consistent with the findings of the last two experiments. It would seem that for probabilities of the CRF contingency below 0.5 there was a tendency for the postreinforcement pause to increase as the probability of the CRF contingency decreases.

Figures 44 - 47, show the effect of varying the probability of the CRF contingency upon the local rate of responding, for each of the animals. With Animal R21, shown in Figure 44, when the probability of the CRF contingency drops to 0.1 a slight 'hump' in the local rate of responding appears early in the 60-sec interval. As the probability of the CRF contingency was increased to 0.3 and 0.5 the size of the distribution gradually increased. Comparing this change in the local rate of responding across conditions, with the relationship between postreinforcement pause and the probability of the CRF contingency (Figure 43), reveals a similarity between the two. As the postreinforcement pause

Figure 43.   Experiment 8 :

The postreinforcement pause on all

conditions, for all animals, as a

function of the probability of the

CRF contingency.   The unconnected

points represent redetermination

conditions.
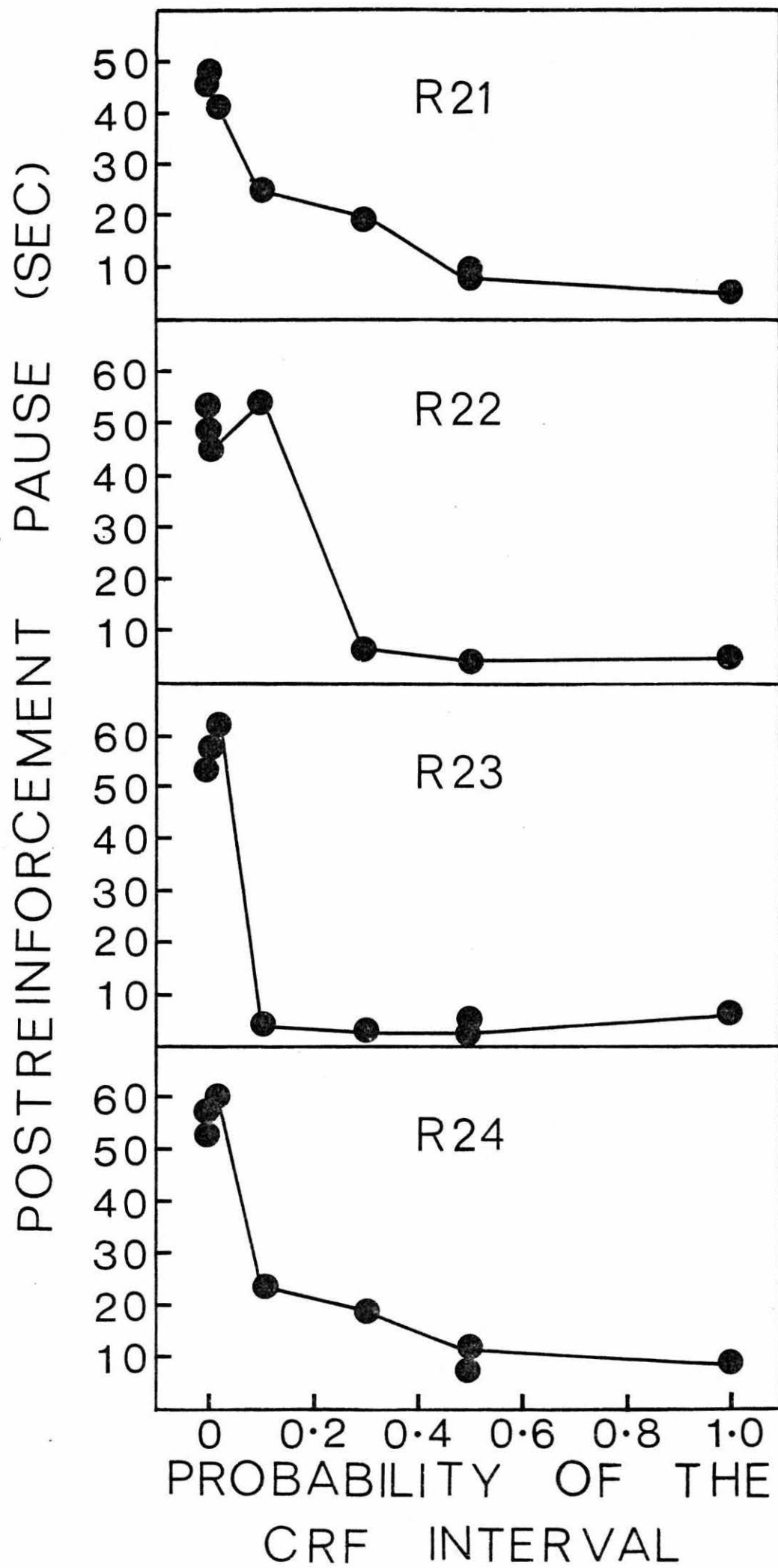
increased, there was a corresponding decrease in the local rate of responding early in the 60-sec interval. This correspondence between the local rate of responding early in the interval and the postreinforcement pause can also be seen in the other three animals, the only exception being the 0.1 probability of the CRF contingency with Animal R22, where it can be seen that there was a slight increase in the local rate of responding early in the interval, and yet there is a postreinforcement pause corresponding to that found on the FI 60 condition. Inspection of the standard deviations of pause durations, presented in Table 9 suggests that this high mean postreinforcement pause could be due to several long pauses that have biased the results. The standard deviation for the pause on the probability of CRF equal to 0.10 condition being exceptionally high.

It would seem, from the results of this experiment, that the effect of having an opportunity for reinforcement very soon after reinforcement is to produce an increased local rate of responding early in the interval. This increase being dependent upon the probability of reinforcement at this part of the interval. The duration of the postreinforcement pause is inversely related to the local rate of responding. This result is consistent with the finding of the two previous experiments reported in this chapter.

These results demonstrate two points of general interest to the performance of animals on irregular temporally defined

Figure 44.　　Experiment 8 :

The local rate of responding on all

conditions, except the CRF condition,

for Animal R21.　　The conditions

marked (R) are redetermination

conditions.

Figure 45.   Experiment 8 :

The local rate of responding on all

conditions, except the CRF condition,

for Animal R22.   The conditions

marked (R) are redetermination

conditions.

Figure 46.   Experiment 8 :

The local rate of responding on all

conditions, except the CRF condition,

for Animal R23.   The conditions

marked (R) are redetermination

conditions.

R23
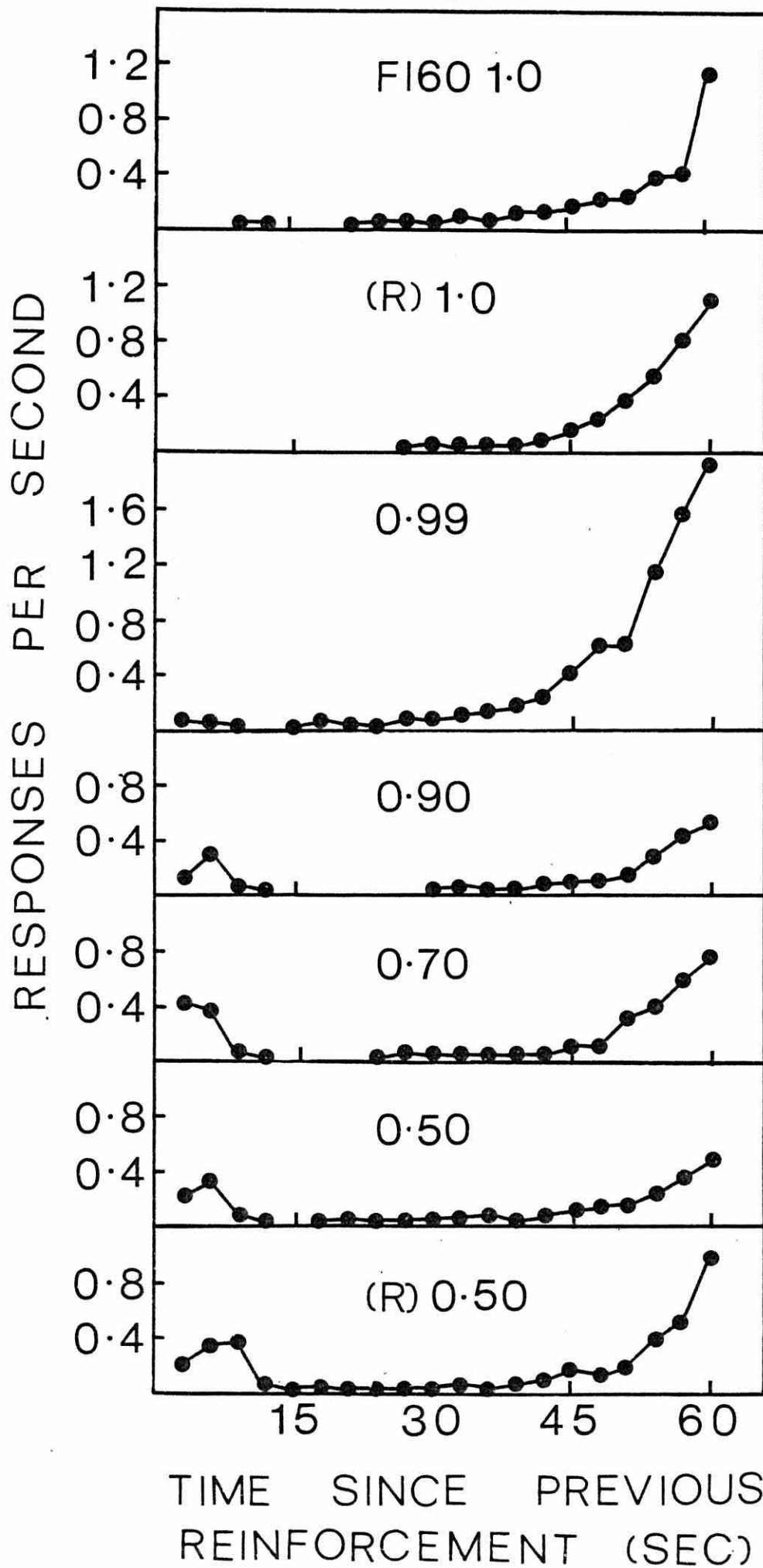
Figure 47.   Experiment 8 :

The local rate of responding on all

conditions, except the CRF condition,

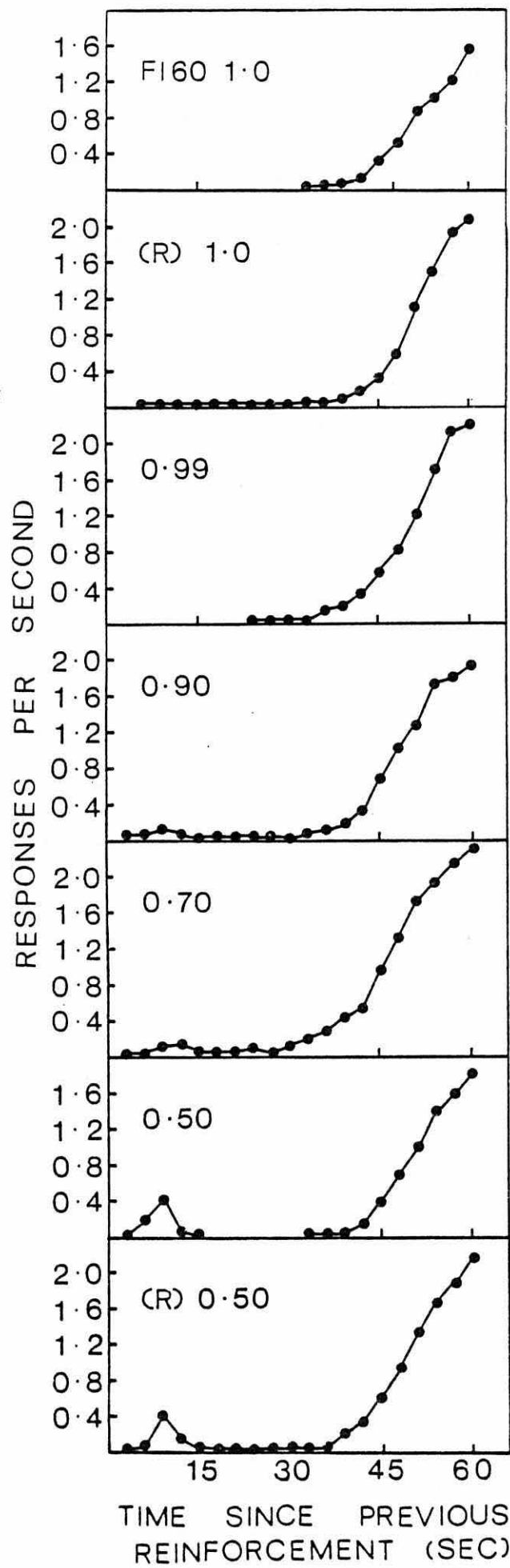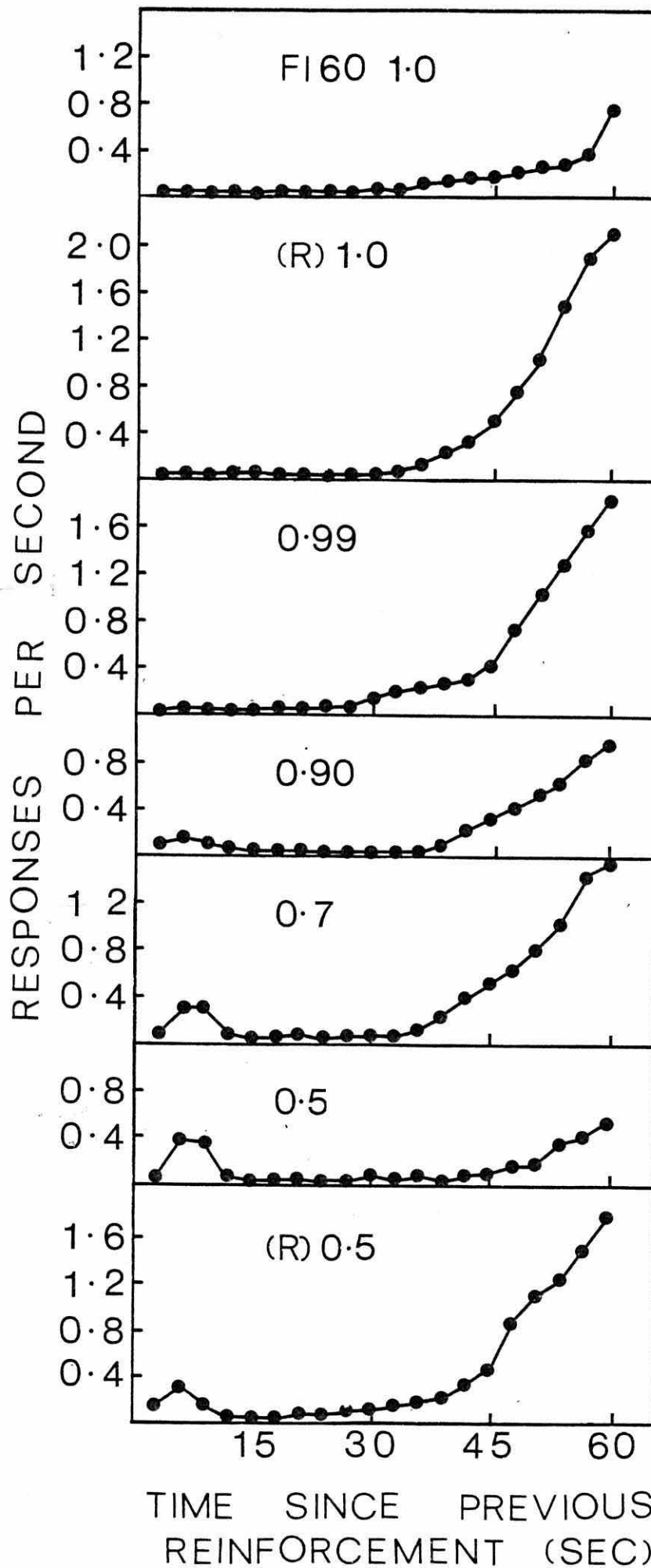for Animal 24.   The conditions marked

(R) are redetermination conditions.
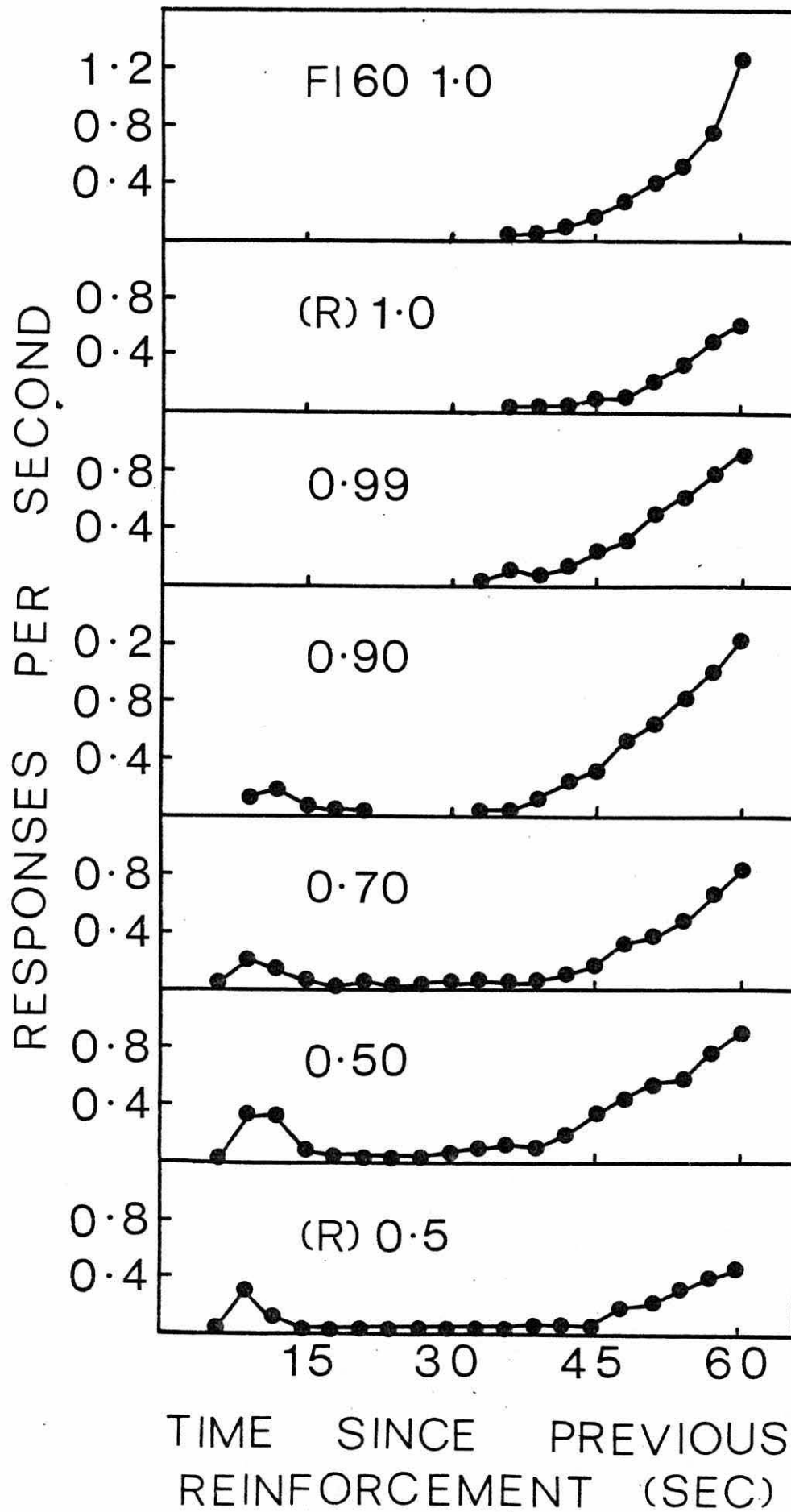
schedules as a whole.   Firstly, they show that if reinforcement
is delivered for the first response after reinforcement, as in the CRF
condition, that there will be a measurable postreinforcement pause
for a few seconds.   This pause is probably due to the animal
completing the consummatory response of eating the food pellet.
Secondly, it demonstrates the effect upon the animal's probability
of making a response   with   various probabilities of immediate
reinforcement.   If the probability of immediate reinforcement
falls to 0.10 or below, then the animal will not tend to make an
immediate response.   This suggests that on VI schedules in which
there is a probability of reinforcement for the first response
after reinforcement, that there will still be a pause unless the
probability of the immediate reinforcement was greater than 0.10.

General Discussion.

The results of the three experiments presented in this
chapter may be summarised as follows.   On a two-valued mixed FI
schedule, the duration of the postreinforcement pause corresponds
to that which would be expected on an FI schedule with a value equal
to the short interval of the mixed FI, provided that the probability
of the short interval is 0.5 or above.   If the probability of the
short interval falls below 0.5, then there is an increase in
postreinforcement pause duration.   It was also shown that there
is a similar relationship between the probability of reinforcement
at the end of the short interval and the local rate of responding

around that region.   When the probability was above 0.5, the local rate of responding around the end of the short interval was about the same as that at the end of the long interval, when the probability of reinforcement was 1.0.   When the probability of reinforcement at the end of the short interval fell below 0.5 there was a decrease in the local rate of responding in that region. These results are consistent with the findings of Catania and Reynolds (1968), in that the local rate of responding at the end of the short interval is related to the local rate of reinforcement at that point which will be reduced by means of decreasing the probability of reinforcement.   It may thus be supposed that the reason why the local rate of responding did not increase when the probability of reinforcement at the end of the short interval was increased above 0.5, was because it produces a sufficient local rate of reinforcement to maintain a local rate of responding at about asymptotical level (cf Herrnstein 1970).

It was shown in the last chapter that the local rate of responding is distributed approximately normally around a point slightly later in time than the end of the short interval.   This finding, taken in conjunction with the findings in the present chapter, may lead to an explanation of the increase in the postreinforcement pause with decrease in the probability of the short interval.   The reduction in probability of reinforcement at the end of the short interval will lead to a reduction in the distribution of local rates about that region, and consequently

a reduced probability of making a response after reinforcement, and,
therefore, a longer pause.   This explanation is consistent with
the inverse relationship found between the local rate of responding
and the postreinforcement pause.

CHAPTER 8.

SUMMARY OF THE FINDINGS AND CONCLUSIONS

Summary.

Experiments I and II investigated the relative influence
of the two intervals making up an evenly probable two-valued mixed
FI schedule upon the duration of the postreinforcement pause and
the local rate of responding. The results of these experiments
showed that the duration of the postreinforcement pause was almost

entirely determined by the duration of the short interval, the
pause being virtually that which would be expected on an FI
schedule with a value equal to that of the short interval in the
mixed FI. There was, however, a slight increase in the duration
of the postreinforcement pause relative to the duration of the
short interval, as the ratio between the two intervals increased
to 1.5. As the ratio between the two intervals increased
above 1.5 there was a decline in the duration of the pause relative
to the short interval. It was suggested that this phenomenon
was due to the animal failing to discriminate the presence of
two different interval values, when the ratio between them was
1.5 or below (cf Rilling 1967).

The general finding that the postreinforcement pause
was mainly determined by the duration of the short interval is
consistent with other research reported in the literature. Harzem,
Lowe and Spencer (1978) found that when a DRL contingency was added
to an FI schedule, i.e. the animal was reinforced for its first
response after reinforcement provided that the postreinforcement
pause had been above a minimum value, the animal's pause was
appropriate to the contingency, either FI or DRL, that would be
expected to produce the shortest pause. Similar results have also
been reported by Logan (1967) using a mixed DRL schedule.

The experiments reported in Chapter 6 investigated the distribution of the local rate of responding maintained by an opportunity for reinforcement in greater detail. The results of Experiment III showed the distribution to be symmetrical in shape and to have something of the appearance of a normal distribution. The pattern of responding up to the end of the short interval was very similar to that found in an FI schedule of the same value as the short interval. These results are consistent with the findings of Killeen (1975) and Lowe and Harzem (1977), who found that the local rate of responding produced by an FI is described very well by the left-hand side of a normal distribution curve. It was also shown from an anlaysis of the pattern of responding during the run time, and from the cumulative records, that this pattern of responding reflects performance in individual intervals.

Experiment IV investigated the influence of the long interval in the mixed FI upon the distribution of local rates of responding about the end of the short interval. The results demonstrated that there must be a critical ratio between the two intervals for a reduction in rate to occur after the first opportunity for reinforcement. Once the inverted U-shaped distribution had developed, the peak of the distribution was entirely determined by the short interval in the mixed FI.

Experiment V investigated the effect of varying the duration of the short interval upon the distribution of local rates of responding. The results showed that the peak and the variability of this distribution was determined by the duration of the short interval. This result is consistent with a Weber-type timing process such as that suggested by Gibbon (1977).

It was argued that the results of the experiments reported in Chapter 6 confirmed Catania and Reynold's (1968) suggestion that the spread of effect of a reinforcement upon the local rate of responding could be thought of as a gradient of temporal generalization.

The experiments reported in Chapter 7 looked at the effect of varying the probability of reinforcement delivered at the end of the short interval, in a two-valued mixed FI schedule upon the pattern of responding maintained by that schedule. Experiment VI studied the effect of varying the relative occurrence of reinforcement at 30-sec, in a mixed FI 30-sec — FI 60-sec schedule. The results showed that, when the probability of reinforcement at the 30-sec point was 0.5 or above, the postreinforcement pause was approximately that which would be expected on an FI schedule of value equal to that of the short interval of the mixed FI schedule. This finding is consistent with those of the previous experiments reported in this thesis. When the probability

of reinforcement at the end of the short interval fell below 0.5 the duration of the postreinforcement pause increased systematically.

Experiment VII looked at the effect of varying the probability of reinforcement at the end of the short interval on a mixed FI 30-sec — FI 120-sec. The difference between the two intervals was great enough in this schedule to produce an inverted U-shaped distribution around the end of the short interval. The results of this experiment showed that the distribution of local rates of responding maintained by the probability of reinforcement at the end of the short interval was related to this probability. It was also found that the postreinforcement pause increased when the probability of reinforcement at the end of the short interval fell below 0.5. When the probability of reinforcement was 0.5 or above the distributions of local rates were very similar at each probability ; when the probability dropped below 0.5 the distribution of local rates, around the end of the short interval, declined, showing that probabilities of below 0.5 would not maintain the same strength of responding as probabilities of 0.5 or above. These results are consistent with the findings of Catania and Reynolds (1968) and could be interpreted in terms of a reduction in the local rate of responding, due to a reduction in the local rate of reinforcement.

The final experiment reported in this thesis, looked at the influence of an opportunity for reinforcement immediately after a reinforcement upon the pattern of responding. Here the results were consistent with the two previous experiments reported in this chapter. The postreinforcement pause on the CRF condition and the condition in which the probability of reinforcement for the first response after reinforcement was 0.5, were equal. When, however, the probability of immediate reinforcement was reduced below 0.5, the general finding was that the postreinforcement pause increased. A similar relationship was found between the local rate of responding maintained by this immediate reinforcement and its probability of occurrence ; the local rate of responding maintained, decreased systematically when the probability of immediate reinforcement fell below 0.5.

The results of the three experiments reported in Chapter 7, taken as a whole, strongly suggest that the postreinforcement pause not only depends upon the duration of the short interval (cf Staddon 1972a) but also upon its probability of occurrence.

Conclusions.

The results of the experiments reported in Chapter 6, together with other evidence, would seem to support Catania and Reynold's hypothesis that performance on an FI schedule may be

thought of as a gradient of temporal generalization. Further
evidence for this comes from the findings of Killeen (1975) and
Lowe and Harzem (1977) that the local rate of responding on FI
may be described by the left-hand side of a normal distribution
curve. It has been pointed out by Rilling (1977) that other
generalization gradients of physical stimuli are well fitted by a
normal distribution.

It has been suggested by Staddon (1972a) that an
animal's behaviour, at any point in a fixed interval, is a function
of its relative proximity to reinforcement. Dews (1970) had
provided some experimental evidence for this. He plotted the
rate of responding relative to the terminal rate of responding at
several proportional points across three FI values, FI 30-sec,
FI 300-sec and FI 3000-sec. The functions for each FI value were
virtually identical. This suggests that the rate of responding at
any point in an FI interval is a consistent fraction of the terminal
rate of responding. So if the terminal rate of responding was
reduced there would be a proportional decrease in rate over the
entire interval. It would follow directly from Catania and
Reynold's (1968) finding that if the local rate of reinforcement at
the end of the fixed interval was reduced by a sufficient amount,
there would be a consequent reduction in the local rate of
responding, which would be proportional across the entire interval.

An alternative way of considering rate of responding is
in terms of the probability of the animal making a response in a
particular unit time. Since it has been shown that the local
rate of responding on an FI schedule is normally distributed, then
it follows that the animal's probability of making a response in a
particular unit time must be normally distributed. So if the
local rate of reinforcement at the end of the fixed interval is
reduced, as in Experiments VI and VII, by means of reducing the
probability of reinforcement at the end of the short interval, then
it follows that there will be a reduction in the probability of the
animal making a response early in the interval and hence an increased
postreinforcement pause. The present results are consistent with
this account.

The Role of Temporal Discrimination.

It was established in Chapter 6 that the local rate of
responding produced on an FI schedule, may be considered as a
gradient of temporal generalization, this implies that temporal
discrimination occurs throughout the entire fixed interval. This
finding is incompatible with explanations of FI performance which
allow for temporal discrimination to occur only in one part of the
interval, either the postreinforcement pause or the run time, for
example, Schneider's (1969) two-state hypothesis, where temporal
discrimination is only considered to occur up to the break point,

and Shull's (1979) suggestion that temporal discrimination only occurs during the run time. Similarly, the present findings are difficult for some explanations in terms of delay of reinforcement, such as those proposed by Dews (1962) and Morse (1966).

Since temporal discrimination occurs throughout the entire fixed interval, it follows that the animal's ability to discriminate time affects all of its behaviour on this schedule. It was argued in Chapter 3 that an animal's ability to discriminate different temporal durations can be best described by Weber's law (cf Stubbs 1968; 1971; Church, Gelly and Lerner 1976), the Weber fraction giving a quantitative measure. For example, Church et al (1976) reported Weber fractions for rats on a temporal discimination task ranging between 0.18 and 0.5 for different animals. Hence, it may be assumed that after the animal has timed a particular duration, it will only be able to discriminate how much time has past to within quite a large margin of error. Thus, it will be in a region of temporal uncertainty, the duration of which will be directly proportional to the amount of time that has past and the temporal Weber fraction for that animal.

It has been pointed out by Staddon (1972a; 1974) that the time marker that animals use on an FI schedule is the delivery of reinforcement, so timing will start when reinforcement is delivered. For the first few seconds after reinforcement the animal will be able to discriminate, to within a few seconds, how much time has past ;

provided it is an FI value of say 30-sec or more, the animal will be able to discriminate that this period is not associated with reinforcement and hence will not respond. As the time since the previous reinforcement increases the region of temporal uncertainty will also increase proportionally. There will, therefore, come a point where the animal will be unable to discriminate whether the amount of time that has past since the last reinforcement is less than the FI value. It may be hypothesised that the animal will make its first response when sufficient time has past for it to discriminate a minimum probability of being reinforced. After the first response has been made, more time will have past and, therefore, the animal will discriminate a slightly greater probability of being reinforced and hence it will respond again. As the discriminated probability of being reinforced increases the rate will also increase (cf Herrnstein 1961; 1970), thus producing the typical scallop pattern of responding.

This explanation of FI performance is consistent with the results reported in the present thesis. For example, it was demonstrated in Experiment IV that for a drop in the local rate of responding to occur between the two opportunities for reinforcement they must be separated by an interval at least equal to the value of the short interval. This would follow from a Weber-type timing process, since, without a relatively large interval between the two opportunities, the animal would be unable to discriminate a region of

no reinforcement. This explanation is also consistent with the results of the experiments, reported in Chapter 7, in which the probability of reinforcement at the end of the short interval was varied. For the animal to respond when it could discriminate the same minimum probability of reinforcement that produces the first response on an ordinary FI, when the actual probability of reinforcement at the end of the interval is reduced, more time would have to pass since the previous reinforcement, and hence the postreinforcement pause would increase.

This explanation can also take account of the finding of Catania and Reynolds (1968), that the local rate of responding is determined by the local rate of reinforcement. On a VI schedule, as time increases since the previous reinforcement, the region of temporal uncertainty will also increase proportionally. After a reasonable amount of time has past since reinforcement, this region will have within it several opportunities for reinforcement, each of which is associated with a particular probability of reinforcement. Since the animal will not be able to discriminate which of these opportunities is coming up next, or which opportunities have past, it may be supposed that they will not act independently upon behaviour. It follows then that all the opportunities for reinforcement in a region of temporal uncertainty will act as a whole upon behaviour, the probability of reinforcement which the animal can discriminate at any one time being the sum of the probabilities of

reinforcement of all the opportunities for reinforcement, within the particular region of temporal uncertainty in which the animal finds itself. This discriminated probability of reinforcement is similar to Catania and Reynold's (1968) concept of local rate of reinforcement, though it does differ in some respects. Catania and Reynolds considered that an opportunity for reinforcement would only affect behaviour up to the mid-point between that particular opportunity and the previous and subsequent ones. The present explanation would have it that opportunities for reinforcement will affect behaviour over the region of temporal uncertainty that the animal is in when the opportunity occurs, which would depend upon the animal's temporal Weber fraction. This was demonstrated by the results of Experiments IV and V where it was shown that spread of the curve of local rates of responding was directly determined by the interval duration.

Further research will be necessary to follow up these ideas, which at present can only be stated tentatively. It is, however, possible to make certain predictions from this idea of Weber timing on interval schedules which could be submitted to experimental test. For example, it would be expected that animals showing relatively small Weber fractions on a task such as that described by Church et al (1976) would produce longer postreinforcement pauses on an FI schedule than would animals that showed larger Weber fractions.

On the whole, the results of the experiments reported in this thesis confirm the importance of temporal factors in determining behaviour on schedules of reinforcement.

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