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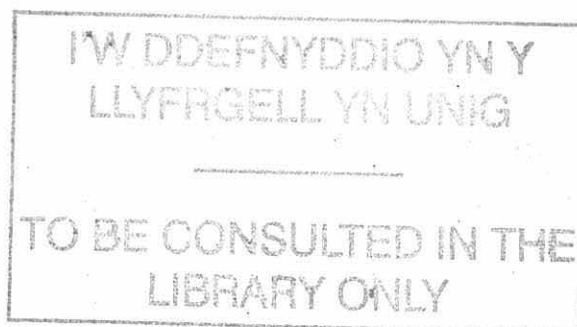University College of North Wales, Bangor

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STIMULUS CONTROL OF TIME-RELATED BEHAVIOUR

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ABSTRACT

Stimulus functions of (i) reinforcing stimuli,
and (ii) responses,were investigated in terms of
their immediate after-effects. In several experiments
rats responded on two-component differential
reinforcement of low rate (DRL) schedules. In these
schedules, designed for the present study, a
response was reinforced only if preceded by a stated
minimum interval of no responding; two such intervals,
(t_1 and t_2,) were specified depending on whether
timing began from (i) reinforcement, or (ii) a non-
reinforced response, respectively. The findings were
as follows:

1. The IRTs which occurred following reinforced
and non-reinforced responses were different and were
appropriate to the minimum IRT requirements related to
these two events.

2. The longer the IRT requirement following a
non-reinforced response the greater was the efficiency
of performance following reinforced responses.

3. The temporal accuracy of responding was not affected by the addition of exteroceptive stimuli to either the t_1 or the t_2 component.

4. When reinforcement was omitted from the t_2 component the temporal accuracy of performance deteriorated.

5. The omission of reinforcement following the first response to occur after each reinforced response resulted in relatively long pauses following reinforcement.

6. Response bursts (i) occurred only following non-reinforced responses, (ii) had a greater probability of occurrence after responses on the t_1 component than after responses on the t_2 component, (iii) occurred with greater probability following t_1 responses as the duration of the t_2 criterion increased, (iv) occurred with a relatively high probability when reinforcement was omitted following some "correct" responses but declined following extended exposure to such omissions.

When the concentration of the milk reinforcer was manipulated on four different schedules, namely DRL, fixed-interval, response-initiated fixed-interval and fixed-ratio, the duration of the post-reinforcement pause was found in each case to be an increasing function of the concentration of the preceding reinforcer. Related changes in response rate were also observed.

These results were discussed with regard to the discriminative and inhibitory properties of reinforcing stimuli and responses in the temporal control of behaviour. The data were also found to be consistent with frustrative non-reward theory (Amsel, 1958; 1962).

CONTENTS

CHAPTER 1

INTRODUCTION

It has been demonstrated that the behaviour
of organisms adjusts to the temporal characteristics
of changes in the environment. Such temporal
adjustment, over relatively long periods of time,
is evident in time-correlated cyclical processes in
many organisms (cf. Cold Spring Harbour Symposia on
Quantitative Biology : Biological Clocks, 1960;
Marler and Hamilton, 1966; Brown, 1969). In addition,
it is known that when temporal constraints are

imposed on the occurrence of environmental events
such as reinforcers, their effects are observed in
the temporal patterning of the behaviour reinforced.
This characteristic of operant responding has been well
documented since the development of temporally-based
schedules of reinforcement by Skinner and his associates
(e.g., Skinner, 1938; Ferster and Skinner, 1957). The
present thesis is an investigation of some of the factors
which determine the temporal regulation of operant
behaviour.

The fixed-interval (FI) schedule is one example
of a temporally-based schedule of reinforcement. On
this schedule a response is reinforced only if a
stated interval of time has elapsed since the preceding
reinforcement. The pattern of responding which
develops consists of a relatively long pause
after the occurrence of the reinforcer followed by
responding which gradually accelerates in rate so that
a high and steady rate is achieved by the time the next
reinforcement occurs. The duration of the pause
following reinforcement, the post-reinforcement pause,
has been found to be proportional to the duration of
the fixed-interval (Sherman, 1958; Harzem, 1968;
Schneider, 1969). This constant proportionality, as
well as the increase in response rate as the next
reinforcement approaches, has been taken as evidence

of temporal discrimination or, more generally, of
behavioural adjustment to the temporal constraints of
the schedule.

Further evidence of such temporal adjustment of
behaviour comes from the pattern of responding which
typically occurs on another frequently used schedule
of reinforcement, namely, the differential reinforcement
of low rate (DRL). On this schedule a response is
reinforced only if a minimum interval has elapsed since
the preceding response; if a response occurs after a
shorter interval it is not reinforced and timing starts
again from that response. Under these conditions the
rate of responding is inversely related to the minimum
interval specified by the schedule, i.e., the longer
the minimum pause required for reinforcement, the
longer the duration of the mean interval separating the
responses.

Although temporal patterning of this sort is
consistently observed on such schedules, the factors
which determine its occurrence are not yet understood.
This may in part be due to the atheoretical tendency
of much research concerned with operant behaviour.
Jenkins (1970) has described the situation as follows:

One might have thought that the publication of
The Behaviour of Organisms (Skinner, 1938) would
set a pattern for systematic and analytical
research on the fundamentals of operant conditioning.
Although this has to some extent been the case,
much research on operant conditioning in the thirty
years since the publication of The Behaviour of
Organisms has taken a different direction. Instead
of checking, revising and adding to the principles
put forth by Skinner in 1938, many have been
satisfied to generate behavioural regularities
by the use of experimental arrangements far too
complex to analyse. In the study of reinforcement
schedules the trend has been toward more and more
complex contingencies of reinforcement (p.106).

An analytical approach to schedule phenomena is adopted

in the present thesis; specifically, an attempt is

made to identify some of the stimuli which control

responding on temporally-based schedules of reinforcement.

Since the formulation of the Law of Effect (Thorndike,

1911), emphasis has been placed on the fact that the

reinforcing stimulus, when presented as a consequence

of a response,"strengthens" or increases the probability

of that response (Skinner, 1938; 1953 b; 1966). In

addition to this, however, the reinforcer might, as a

cue, be expected to directly affect the events which

immediately follow its occurrence. Likewise, a response,

whether reinforced or unreinforced, might affect the

events which it immediately precedes. On FI and DRL

schedules, for example, since exteroceptive stimuli

signalling the availability of reinforcement are not

present, the possibility exists that it is either
reinforcers or responses, or both, which function as
stimuli on these schedules.

The term "stimulus control" has generally been
used to refer to the phenomenon whereby the rate
of responding varies with reference to the presence
or absence of a particular stimulus (e.g., Terrace,
1966; Ferster and Perrott, 1968). However, in both
FI and DRL schedules, reinforcers and responses occur
briefly, and responding cannot be said to occur in the
presence of either event. This has led some writers
to postulate the existence of internal stimuli (Anger,
1963). Thus either a response or a reinforcer may
produce some change within the organism, and the
duration of this internal stimulus may serve as a
discriminative stimulus for responding. Although it
appears likely that physiological events may have
stimulus properties on schedules of reinforcement, it
does not seem helpful to account for behaviour patterns
by reference to such inferred events, without
exhaustively investigating the control which may be
exerted by observable environmental stimuli (cf. Morse,
1966).

This thesis is concerned with a kind of stimulus
control which involves the relationship between a
stimulus and the response which follows it in

time. Staddon (1972) has termed this "temporal control" and has described it as follows: "...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...(p.213)".

An example of temporal control is the relationship between the reinforcing stimulus and the response which terminates the post-reinforcement pause on the FI schedule (cf. Chapter 2). However, responding on FI schedules is difficult to analyse in these terms since a relatively large number of responses occur in each fixed interval. It may be the case that each response functions as a discriminative stimulus for the next response, in the manner of a response chain (Ferster and Skinner, 1957), but such relationships are difficult to demonstrate (Kelleher, 1966). Moreover, several experiments have shown that interruption of responding on FI schedules does not disrupt the typical FI response pattern (Ferster and Skinner, 1957; Dews, 1962). This indicates that response-chaining is not necessary for positively accelerated responding on FI and suggests that other interpretations of this response pattern are required (Kelleher, 1966).

The stimulus controlling each response may be more readily identifiable in DRL schedules. Staddon (1972), for example, has proposed that the spacing of responses in time in accordance with the minimum inter-response time requirement of a DRL schedule may represent temporal control of each response by the preceding response. Experiments to be reported here investigated the extent to which, on DRL schedules, reinforced and non-reinforced responses maintain temporal control of the responses which follow them.

In conventional DRL schedules there are two programmed consequences for a response: (i) reinforcement/non-reinforcement, and (ii) delay in the availability of reinforcement for a given period. In previous studies the delay or resetting contingency has been the same after responses meeting the DRL requirement (i.e., reinforced responses) as after responses falling short of the requirement (i.e., non-reinforced responses). In the present study a two-component DRL schedule was devised, in which the inter-response time (IRT) requirements after reinforced and non-reinforced responses were different, thus making possible an assessment of the stimulus functions of the reinforcer and responses in controlling specific IRTs. The two-component DRL schedule also permitted analysis of the

behavioural effects of different "delays" contingent
on responses falling short of the initial DRL
requirement, and thus it was expected to clarify the
role of such contingencies in conventional DRL
schedules.

In Chapter 2 the literature relating to stimulus
effects of the reinforcer on some basic schedules of
reinforcement is considered and Chapter 3 presents
evidence regarding the stimulus effects of reinforcers
and responses in DRL schedules. The literature
relating to general aspects of performance on DRL
schedules is also reviewed in Chapter 3,

In Chapter 5 experiments are described in which
the behavioural effects of two-component DRL schedules
were investigated; the minimum IRT requirement after
reinforcement was held constant, while the IRT
requirement after non-reinforced responses was varied
over a wide range of values. Chapter 6 is concerned
with a further analysis of stimulus control in two-
component DRL schedules; the stimulus properties of
reinforcers and responses were evaluated by observing
the effects of (i) the addition of a differential

stimulus to each component, and (ii) systematic omission
of the reinforcer.

The antecedent stimulus effects of changes in
the magnitude of reinforcement were next considered.
The literature relating to the effects of magnitude
of reinforcement on operant responding is reviewed
in Chapter 7.   In Chapter 8, experiments are described
where the concentration of the milk reinforcer was
varied on DRL, FI, response-initiated fixed-interval
(tandem FR 1 FI) and fixed-ratio (FR) schedules.   As
with the two-component DRL schedules, responding on
these schedules is analysed in relation to two time
periods: (i) the time from reinforcement to the first
response, and (ii) the time from the first non-reinforced
response to the next reinforcement.

CHAPTER 2

THE ROLE OF THE REINFORCER AS A STIMULUS ON

SCHEDULES OF REINFORCEMENT

In a discussion of the effects of reinforcement,
Reid (1957) has argued that "Reinforcing events are
sources of stimulation, whatever else they may be, and
therefore, in learning situations, they may be expected
to gain some degree of stimulus control over the
performance of the learned response (p.202)". The present
chapter investigates the evidence for stimulus control
by the reinforcer on some of the basic schedules of
reinforcement.

CONTINUOUS REINFORCEMENT

On a continuous reinforcement schedule (CRF)
every response is reinforced. That the reinforcing
stimulus on CRF acts not only to reinforce behaviour
but also gains a degree of stimulus control over the
response that it reinforces has been demonstrated in
experiments reported by Reid (1957). In one experiment
six rats were reinforced for two sessions by the
delivery of a food pellet following every bar-pressing
response (CRF). There followed three extinction sessions
when lever-pressing produced the usual noise but no
pellets of food. At the end of the last extinction
session, when responding was minimal, a pellet of food
was dropped into the food dish. Every animal ate the
food and 5 out of the 6 pressed the lever within the
following one minute (min) observation period, no lever
presses having occurred during the equivalent observation
period before the delivery of food. Other stimuli, such
as tapping the box, flicking the lighting and sounding a
buzzer, were also presented in a similar manner but were
not successful in restoring the extinguished response.

A similar experiment was carried out with pigeons
as subjects (Reid, 1957). When a maple pea - the
reinforcer - was dropped into the food pan during extinction

all birds ate immediately and five out of six pecked
at the response key within 10 seconds (sec) of eating.
Reid reports that the bird which failed to peck the
key was given a second trial and the presentation of the
free reinforcer on this occasion produced a response
within the 10-sec interval. No responding had occurred
by any of the birds in the equivalent periods before
the occurrence of the free food. Similar experiments
using human subjects, with both operant and respondent
behaviours, (i.e., operation of a slot machine and
eyelid response, respectively) showed similar recovery of
the conditioned response when free reinforcers were
delivered during extinction (Reid, 1957). Skinner (1938,
Pp.80-81) also mentions a case of "reinforcer-produced"
responding in a rat during extinction of CRF performance.

These experiments suggest that in the course of
training on the CRF schedule the reinforcing stimulus
not only increases the probability or rate of the
selected response but comes to control responding directly
so that non-contingent presentation of the reinforcer
produces a response or responses. The length of the
interval between the occurrence of reinforcement and the
next response, both during CRF and when the reinforcer
was presented "free", was not reported in the experiments

discussed above. Some of the studies described in the
following sections provide evidence of the temporal
relationship between reinforcers and responses on other
schedules of reinforcement.

FIXED-INTERVAL

On an FI schedule of reinforcement the first
response is reinforced after a stated interval of time
has elapsed. The event which initiates this interval
of time is usually the preceding reinforcement. The
performance typically generated by FI schedules consists
of a pause after each reinforcement, followed by a
gradually accelerating rate of responding which is
terminated at the next reinforcement. This pattern
of responding is often referred to as the FI scallop.
After extended exposure to short fixed intervals, a
break-and-run pattern is often observed, i.e., a pause
after reinforcement followed, in the period
after the pause until the next reinforcement (the running
time), by a rapid transition to a constant rate of
responding (e.g., Schneider, 1969).

A number of studies of the pattern of responding
on FI schedules have suggested that the post-reinforcement
pause and the rate of responding in the running time
(the running rate) are separately determined. According
to Schneider (1969) and Shull (1970 b), the rate and
topography of responding which occurs in the running time
is a function of the responding prevailing at the moment
of reinforcement. It has been argued, however, that the
pause after reinforcement is determined by other factors.
For example, the post-reinforcement pause on FI has
frequently been accounted for in terms of the antecedent
stimulus effects of the reinforcer (Ferster and Skinner,
1957; Dews, 1970; Kling and Schrier, 1971; Nevin, 1973).
According to Ferster and Skinner (1957) the reinforcing
stimulus serves also as a discriminative stimulus on the
FI schedule, setting the occasion for non-reinforcement.
They wrote as follows:

> The stimulus associated with the presentation of
> a reinforcer and with the appropriate consummatory
> behaviour (eating, cleaning, etc.) enter into the
> fixed-interval contingencies in an important way.
> Because they constitute an occasion upon which a
> response is never reinforced, a low rate quickly
> develops after reinforcement. The duration of
> this control is in part a function of the temporal
> properties of the stimuli. Residual stimuli - from
> food in the mouth, swallowing, etc. - may extend
> past the moment of reinforcement. Other behaviour
> may be set in motion (e.g., washing for the rat)
> which may also control a low rate of responding
> because of its relation to non-reinforcement. Very
> roughly speaking, the effect of reinforcement as a
> stimulus of this sort appears to last for 30 seconds

for the pigeon. The effect is to start the
new interval with a period of zero or a very
low rate of responding (Pp.134-135).

Again, Skinner (1953 a) wrote: "After reinforcement
the pigeon pauses briefly ...This is due to the fact
that under a fixed-interval schedule no response is
ever reinforced just after reinforcement. The organism
is able to form a discrimination based upon the stimuli
generated in the act of eating food. So long as the
stimulation is effective the rate is low (p.72)".

Ferster and Skinner (1957) 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 covers
only situations in which the stimulus has a positive
discriminative function (S^D or S^+), negative discriminative
control also occurs where, in the presence of a stimulus
(S^Δ or S^-), responses are not reinforced (Ferster and
Skinner, 1957). The reinforcer on FI, according to
Ferster and Skinner, functions as a negative discriminative
stimulus, "setting the occasion" for non-reinforcement.

A feature of Ferster and Skinner's definition is
that it stipulates that a discriminative stimulus is
"(one) in the presence of which" responding is reinforced.

That the stimulus has to be present in order for it
to exercise discriminative control probably led
Ferster and Skinner to hypothesise that on the FI
schedule residual stimuli, from food in the mouth etc.,
are present for approximately 30 sec after the
presentation of the reinforcer and control a low rate
of responding during this period. However, post-
reinforcement pauses of longer duration than 30 sec
have been reported, e.g., post-reinforcement pauses
of more than an hour's duration on long FIs of up to
24 hours (Dews, 1965). In addition, the duration of
the post-reinforcement pause on FI is a positive
linear function of the duration of the interval specified
by the schedule (Sherman, 1959; Harzem, 1968; Schneider,
1969). A pause also occurs after a stimulus
presented in lieu of reinforcement on FI (Ferster and
Skinner, 1957; Kello, 1972; Staddon, 1972). According
to this evidence the ongoing effects of residual stimuli
associated with the reinforcer cannot wholly account for
the post-reinforcement pause on the FI schedule.

There are two alternative explanations. It has been
thought possible that the positive relationship reported
between the fixed interval duration and the duration of
the pause after reinforcement may be due to the increase
in the number of responses in the longer fixed intervals

(Neuringer and Schneider, 1968). On the other hand,
post-reinforcement pause duration may be directly
determined by temporal factors. Both these explanations
have been submitted to experimental test.

The procedures used in studies concerned with this
problem have involved the manipulation of response
rates in the interval or just before reinforcement,
without changing the amount of time between reinforcements.
Farmer and Schoenfeld (1964 b), for example, added a
DRL contingency to an FI schedule in which a response
was reinforced (i) if a given fixed interval had elapsed
since the preceding reinforcement, and (ii) if the interval
separating that response from the preceding response
exceeded a specified time. This contingency produced
a reduction in the rate of responding during the running
time but the duration of the post-reinforcement pause
remained unaffected. Other procedures have included:
imposing a brief blackout after each unreinforced
response (Neuringer and Schneider, 1968); adding a
small fixed-ratio requirement after the interval has
elapsed (Killeen, 1969); requiring only one response
anywhere in the fixed interval to produce reinforcement
at the end of the interval (Shull, 1970b); changing the
response unit from a single response to a fixed number
of responses (Shull, Guilkey and Witty, 1972). In all

the studies the duration of the post-reinforcement pause
was found to be related to the time between reinforcements,
regardless of the additional response/reinforcement
dependencies.

Staddon (1969) has suggested that in FI schedules
the reinforcer acts as an inhibitory stimulus*, controlling
a low rate of responding for a period of time after its
presentation, after the fashion of Pavlov's inhibition
of delay. Pavlov (1927) reported that when the
unconditioned stimulus (UCS) was delayed for 3 min
following the occurrence of 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 effects of the CS. Evidence in
support of Staddon's hypothesis comes from reinforcement
omission experiments (Staddon and Innis, 1966; Innis
and Staddon, 1969) where it has been found that response
rate is higher if occasional reinforcements are omitted
on FI than if all reinforcements are presented; the
principal effect on response rate is produced by the
reduction in the duration of the pauses in the intervals

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* 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 'reinforcement') develops the
capacity to decrease performance below the level occurring

following reinforcement omission.

Studies which have demonstrated "disinhibition"
effects on fixed-interval responding, analogous to
Pavlov's "disinhibition of delay", also provide
evidence for an inhibitory effect of the reinforcer on FI
(Flanagan and Webb, 1964; Singh and Wickens, 1968;
Hinrichs, 1968; Malone, 1971). These experiments
show that when a novel stimulus is presented early
in the fixed interval the effect is a reduction in
the duration of the post-reinforcement pause and an
increase in response rate in this part of the interval,
suggesting that the inhibitory effect of the reinforcing
stimulus, which normally controls a pause, is in turn
inhibited by the novel stimulus (external disinhibition).
When a novel stimulus is presented later in the fixed
interval, the effect is to decrease the response rate
(external inhibition; Hinrichs, 1968).

Recently, Wilkie (1974) has provided strong evidence
for the existence of inhibitory control early in the
fixed interval. In this study pigeons responded on an
FI schedule in the presence of a stimulus, which consisted

when that stimulus is absent (Pp.6-7)". In the
present thesis the term "inhibitory stimulus"
also refers to any stimulus which suppresses
responding.

of a line projected onto the response-key. Training
sessions were followed by dimensional stimulus control
test sessions during which the orientation of the line
present throughout the fixed interval was varied.
U-shaped (inhibitory) gradients of responding, with
minimum responding occurring in the presence of the
training stimulus, were obtained in the early part of
the interval. Inverted U-shaped (excitatory) gradients
of responding, with minimum responding occurring in the
presence of the training stimulus, were observed in the
terminal part of the fixed interval. In one experimental
condition reinforcement was occasionally replaced by a
brief blackout stimulus; it was found that when the
preceding interval had ended in blackout, inhibitory
gradients did not occur in the following interval.
This evidence suggests that inhibitory effects are
present early in an interval on FI and that these effects
are dependent upon the occurrence of the preceding
reinforcer.

Another way of investigating the inhibitory after-
effects of reinforcement is to present a non-contingent
reinforcer in the course of an interval. Such a procedure
was adopted in a study by Logan and Ferraro (1970) in which,
on a small number of probe-intervals, they presented a

"free" reinforcer midway through the 30-sec fixed interval. The effect of this free reinforcer was apparently to reset the animals "clock", as it produced a pause and a subsequent pattern of responding similar to that which normally occurred when the animal was reinforced at the end of an interval. The experimenters concluded : "The evidence is unequivocal: behaviour following free rewards is most analogous to that following earned rewards, precisely as one would expect if a new interval were initiated by that reward even though it occurred at an unaccustomed time and independent of response (p.121)".

A paradoxical feature of the studies considered so far is that the reinforcer, though possessing inhibitory after-effects, also maintains responding, _i.e._, if reinforcement is totally removed the behaviour will extinguish. Thus, the reinforcer produces a decrease in responding early in the interval relative to the rate of responding occurring later in the interval. Skinner and Morse (1958) compared the durations of the pauses which occurred in the course of wheel-running, with rat subjects, when running was unreinforced and when it was reinforced on an FI schedule. The post-reinforcement pauses which developed under the FI schedule were longer

than the pauses which occurred during unreinforced running. It appears that, in this case, reinforcement depressed responding relative even to the "baseline" rate of responding which occurred in the absence of reinforcement.

There is some evidence which indicates that the period following reinforcement has aversive and "emotional" characteristics. For example, Brown and Flory (1972) found that the stimulus present during the post-reinforcement pause on an FI schedule acted as a negative reinforcer; pigeons pecked a key to remove a stimulus associated with an FI schedule of food reinforcement and most of these "escape" responses were made early in the fixed interval. Elicited aggression has frequently been reported to occur in response to aversive stimulation (Ulrich and Azrin, 1962; Azrin and Holz, 1966), and Richards and Rilling (1972) report that when pigeons were given the opportunity to attack a restrained target, attack rates were higher while performing on an FI schedule of positive reinforcement, than during operant level sessions; most aggression occurred during the post-reinforcement pause in key pecking. As it has frequently been suggested that inhibitory control is aversive and produces "emotional" behaviour

(Terrace, 1966; Hearst, 1972; Terrace, 1972; Richelle, 1972), these experiments provide additional, though indirect, evidence that the reinforcer has inhibitory after-effects on FI schedules.

Catania and Reynolds (1968) and Staddon (1972) have pointed out that the reinforcer on FI is normally the best predictor of non-reinforcement and thus, through conditioning, comes to inhibit responding for a period of time following its occurrence. It is also possible, however, that the reinforcer, as well as being a conditioned inhibitory stimulus on FI, may also have unconditioned inhibitory effects. Experimental evidence that this may be the case comes from percentage reinforcement studies, in which on an FI schedule the reinforcer is replaced by a neutral stimulus on some occasions. In such an experiment, Staddon (1972) used an FI baseline schedule: intervals ended with reinforcement (S^R) or a brief blackout (S^N) with equal probability, but the conditional probability of an interval both beginning and ending with S^N was either 0.9 under one condition, or 0.1 under another. As the brief blackout stimulus in this situation predicts a period of non-reinforcement it also, along with the reinforcer, comes to control a pause. As the prediction by S^N of non-reinforcement

was stronger in the 0.9 condition, there was not surprisingly a longer pause after S^N under this condition than under 0.1. However, the duration of the pause following S^N in either the 0.9 or the 0.1 condition was never as long as that following S^R. The longer pausing after S^R in the 0.9 condition is particularly remarkable as here S^N was a much better predictor of non-reinforcement than was S^R, which was almost invariably followed by S^R.

According to Staddon (1972), the longer pausing which occurs after S^R than after S^N is due to memory factors; the animals remember the reinforcing stimulus better than a neutral stimulus and the former therefore continues to inhibit responding for a longer period of time. Alternatively, it may be suggested that the reinforcer is simply a more effective discriminative or inhibitory stimulus than a neutral stimulus, due perhaps to the greater intensity of stimulation provided by the reinforcer.

FIXED-RATIO

In a fixed-ratio schedule of reinforcement a set number of responses is followed by the reinforcing stimulus. Performance on this schedule typically consists of a pause after reinforcement followed by a constant and relatively high rate of responding until the occurrence of the next reinforcer.

As with the FI schedule, performance on the FR schedule may be considered in relation to (i) the post-reinforcement pause, and (ii) responding in the running time (Powell, 1970; Staddon, 1972). It has also been suggested that the running rate is a function of responding occurring at the time of reinforcement while the post-reinforcement pause is a function of different variables (Morse, 1966; Staddon, 1972).

The reinforcer on the FR schedule may act as a discriminative stimulus, as a response is never reinforced just after a previous reinforcement (Ferster and Skinner, 1957). Thus the operation of the magazine and the ingestion of food are stimuli which set the occasion for the absence of reinforcement and as such

control a low rate of responding. As Ferster and Skinner (1957) point out, this explanation may not be complete; like any other stimulus, the S^Δ effect of the reinforcing stimulus on FR may extend beyond its termination.

The duration of the pause after reinforcement is a function of the ratio requirement (Boren, 1961; Felton and Lyon, 1966; Powell, 1968). It is possible therefore, (i) that the number of responses in a fixed ratio may also serve as a discriminative stimulus controlling the duration of the post-reinforcement pause (Ferster and Skinner, 1957), and/or (ii) that time since reinforcement may be a controlling factor as, after reinforcement, a response cannot be reinforced within a shorter period of time than that required to count out the ratio; this period of time covaries with the number of responses required by the schedule (Ferster and Skinner, 1957; Nevin, 1973).

Even though there are no explicitly programmed temporal contingencies on FR schedules, temporal factors nevertheless appear to be of importance in determining the duration of the post-reinforcement pause. For example,

Berryman and Nevin (1962) trained rats on an FR schedule,
an FI schedule, and four intermediate interlocking
schedules*. They found that the post-reinforcement pause
was a constant fraction of the time between reinforcements,
regardless of whether reinforcement was programmed on a
ratio schedule, on an interval schedule or on an
interlocking schedule.

Neuringer and Schneider (1968) attempted to evaluate
the relative importance of inter-reinforcement time, and
the number of responses between reinforcements, in
determining the duration of the post-reinforcement pause,
by varying each of these factors independently. They
presented a blackout, i.e., houselights in the experimental
chamber were switched off and reinforcement was not
available, after each non-reinforced response under both
FR and FI schedules. The manipulation of blackout duration
on FR caused the inter-response time to vary without
affecting the number of inter-reinforcement responses,
while on FI the effect was to vary the number of responses
in an interval but not the duration of the inter-reinforcement
interval. On FR the duration of the post-reinforcement

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* An interlocking schedule is one in which the reinforcement
is determined by two schedules, where the setting of one
schedule is altered by the progress made in the other.
For example, in the schedule interlock FI 20 FR 10, if
the animal responds fast, reinforcement may be delivered
on the FR schedule, but if 20 sec have elapsed before the
ratio is completed then the next response is reinforced.

pause increased linearly with inter-reinforcement time, whereas the post-reinforcement pause remained constant on the FI schedule. These results suggest that the duration of the post-reinforcement pause on FR and FI schedules is controlled by temporal factors and is not influenced by the number of responses emitted between reinforcements (Neuringer and Schneider, 1968). These findings received further support in a study by Killeen (1969). Pigeons were placed on various FR schedules while yoked birds received reinforcement on an FI-like basis, although the intervals were not precisely constant. No difference was found between the post-reinforcement pause duration of pigeons responding on FR and the yoked (interval) control birds.

These studies indicate that the reinforcer may have similar temporal inhibitory effects on FR schedules as it does on fixed-interval. In this regard, it has been shown that the effect of omitting the reinforcer occasionally on FR schedules is to increase response rate in the interval following reinforcement omission, this increase in rate being principally a function of a reduction in pause duration (McMillan, 1971; Henke, 1973).

There is also evidence that there are aversive
characteristics related to the FR schedule, particularly
during the post-reinforcement pause, which may be regarded
as indirect evidence of inhibitory control (Terrace,
1966; Hearst, 1972; Richelle, 1972). Experiments by
Azrin (1961) and Thompson (1964; 1965) have shown that
subjects will terminate the FR stimulus by making an
alternative response, the consequence of which is time out
(TO) from the schedule contingencies for a stated period,
and that increasingly more time is spent in TO as the FR
is increased in value; "escapes" are typically restricted
to the post-reinforcement pause of the FR schedule.
Elicited aggression has also been recorded on FR and has
been found to occur primarily during the post-reinforcement
pause (Hutchinson, Azrin and Hunt, 1968; Gentry, 1968;
Cherek and Pickens, 1970).

Cruse, Vitulli and Dertke (1966) have demonstrated
stimulus control by the reinforcer of both FR and FI
performance within a single schedule. In their experiment,
the delivery of a standard laboratory food pellet as a
reinforcer initiated a requirement of 30 responses, and
the delivery of a sucrose pellet initiated a fixed-
interval requirement of 3 min. Both reinforcers alternated
in variable runs of one, two or three reinforcers of the

same type. They found very precise stimulus control by the different reinforcers; after sucrose reinforcement a long post-reinforcement pause occurred, appropriate to the FI 3-min schedule, while after the standard pellet there was a shorter post-reinforcement pause, typical of FR 30 performance. The controlling relations were also reversed, i.e., the sucrose pellet was followed by the FR requirement and the standard pellet by FI, and performance changed accordingly.

Although the studies discussed above point to a similarity in the temporal inhibitory effects of the reinforcer on FR and FI schedules, many of the experimental tests for such effects on FI have not been conducted on the FR schedule, e.g., on "disinhibition" effects of novel stimuli (Hinrichs, 1968; Malone, 1971), on dimensional inhibitory control of a stimulus associated with time after reinforcement (Wilkie, 1974), and on pause-producing effects of non-contingent "probe" reinforcers (Logan and Ferraro, 1970). The absence of such evidence is probably due to performance on the FR schedule not usually being considered as temporally-based. The account presented here on the other hand, suggests that the reinforcer on the FR schedule may have temporal

inhibitory after-effects similar to inhibitory effects on FI schedules. This is one of the issues to be considered in the present thesis.

VARIABLE-INTERVAL

In a variable-interval (VI) schedule the intervals between reinforcements vary from one reinforcement to the next in a random or nearly random manner (Ferster and Skinner, 1957). The schedule is usually specified in terms of the mean inter-reinforcement interval. The same mean inter-reinforcement interval, however, may be produced by different distributions of intervals. In an arithmetic VI the intervals are derived from a progression in which successive terms differ by an additive constant, while on a geometric VI the terms differ by a multiplicative constant and on a random-interval schedule the first response which occurs after a specified recycling time interval (T) has elapsed is reinforced with a specified probability (P).

Traditionally VI schedules have been thought to produce a constant rate of responding throughout each interval and to involve little or no pausing after

reinforcement (Nevin, 1973). For example, Ferster and
Skinner (1957) state that the VI schedule "is designed
to produce a constant rate (p.326)". There is, however, evidence
which indicates that whether a pause occurs after
reinforcement is dependent on the distribution of
intervals contained in any particular VI schedule.
Ferster and Skinner (1957) observed that on an arithmetic
VI schedule, pausing after reinforcement was greatly
reduced when several very short inter-reinforcement
intervals were included in the schedule. Similar results
have been reported by Catania and Reynolds (1968).

The duration of the post-reinforcement pause is
also a function of the mean inter-reinforcement
interval on VI. Lachter (1970), using a random-interval
schedule in which P was held constant and T varied
from 0 to 24 sec., found that post-reinforcement pause
duration was a monotonic increasing function of the
mean inter-reinforcement interval ($\frac{T}{P}$). Martin (1971)
has shown a similar relationship between the pause after
reinforcement and mean inter-reinforcement interval when
T as held constant at 30 sec and P varied. It thus
appears from these studies, that on the VI schedule also,
to the extent that the reinforcing stimulus initiates a

period of non-reinforcement, a pause occurs after
reinforcement. For example, on a random-interval VI
where T is 10 sec, when reinforcement occurs it sets
the occasion for a period of non-reinforcement of at
least 10 sec; if T is increased, then the period of
predicted non-reinforcement is also increased, which in
turn is reflected in longer post-reinforcement pauses.
If T is held constant at 10 sec and P decreased, then,
following reinforcement, the probability of a period of
non-reinforcement occurring longer than 10 sec is
increased. Again this would appear to be reflected in
a related increase in the duration of the post-reinforcement
pause.

The evidence from these VI studies indicates that
the reinforcer may act as a temporal inhibitory stimulus
on this schedule. Few studies on VI performance, however,
have recorded after-effects of reinforcement. McMillan
(1971) using a VI 60-sec schedule with pigeons, found
that when 50% of reinforcements were omitted and replaced
by a brief blackout stimulus, pausing after the blackout
was longer than after reinforcement, which was also
accompanied by a blackout. Though this appears contrary
to what would be expected if reinforcement had inhibitory
after-effects, i.e., the removal of the inhibitory stimulus

should on this account have produced a decrease in pause
duration, subsequent studies have not confirmed these
findings. For example, in a recent study (Thomas and
Blackman, 1974) it was reported that pigeons' pauses
after reinforcement were longer than pauses after signalled
reinforcement omission. Higson (personal communication),
using rats as subjects, has found effects similar to
those of Thomas and Blackman (1974) when reinforcement
was occasionally omitted on different VI schedules.
Differences in the experimental parameters may have
contributed to the discrepancy between McMillan's (1971)
results and those of the more recent studies (Blackman
and Thomas, 1974). The recent findings are, of course,
consistent with the suggestion that the reinforcer has
inhibitory after-effects on the VI schedule.

A study by Dove, Rashotte and Katz (1974) provides
further support for the inhibitory hypothesis. In common
with aggression studies that have been conducted with
FI and FR schedules, they found that attack rates of
pigeons on a VI schedule of food reinforcement were a
function of mean inter-reinforcement interval and
occurred mainly following reinforcement.

VARIABLE-RATIO

In a variable-ratio (VR) schedule reinforcement
occurs after a specified number of responses, the
number varying from reinforcement to reinforcement.
The schedule produces different performances, depending
upon the distribution of numbers of responses required
for reinforcement (Ferster and Skinner, 1957). Such
distributions may be obtained from arithmetic or
geometric progressions, or the schedule may specify
the probability with which any particular response will
be reinforced, i.e., a random-ratio schedule.

The VR schedule, like the VI schedule, is frequently
regarded as generating a constant, though high, response
rate between reinforcements, with no consistent pause
occurring after reinforcement (Staddon, 1972; Nevin,
1973). In many cases the time from reinforcement to the
first response after reinforcement has not been recorded
on this schedule (e.g., Brandauer, 1958; Sidley and
Schoenfeld, 1964). However, a study by Farmer and
Schoenfeld (1967) shows that when the probability of
reinforcement is systematically varied on a random-ratio
schedule, the pause after reinforcement gets longer as the
probability of reinforcement is decreased, i.e., as mean
ratio is increased.

This relationship between ratio value and
post-reinforcement pause raises similar questions as
have been encountered on other schedules, regarding
the determinants of post-reinforcement pause duration.
An analysis in terms of control by temporal variables
has been tentatively presented for post-reinforcement
pause functions on FI, FR and VI. A similar analysis
may apply to performance on the VR schedule.

Reinforcement on VR sets the occasion for a
period of non-reinforcement which will be at least as
long as the time taken by the animal to emit the
shortest ratio. As the incidence of short ratios is
decreased, the prediction by the reinforcing stimulus
of a longer period of non-reinforcement is enhanced.
This would appear to be reflected in longer pauses
occurring after reinforcement (Farmer and Schoenfeld,
1967). The reinforcer on a VR schedule thus may act
as an inhibitory stimulus for a period of time after its
occurrence, the duration of such control being determined
by the distribution of ratio requirements. The finding
that schedule-induced aggression occurs on VR schedules,
but only following reinforcement (Webbe, De Weese and
Malagodi, 1974), is consistent with this account.

In the case of the VR schedule there remains, however, a further problem. If the after-effect of the reinforcer is related to the initiation of a period of non-reinforcement by the reinforcer, this same effect should also be observed following all responses whether reinforced or not. This is because the same period of non-reinforcement is predicted by every response on the random ratio schedule; the probability of reinforcement is determined independently for each response. Though post-reinforcement pause duration increases as a function of the mean ratio value, the mean time interval between all other responses remains constant (Farmer and Schoenfeld, 1967). This suggests that increasing the ratio value affects the stimulus function of the reinforcer but such an effect does not extend to non-reinforced responses.

This raises the following question: can single non-reinforced responses serve as stimuli with temporal control of other responses, on schedules of reinforcement? The notion that responses have stimulus properties which are effective in controlling other responses is an old idea in psychology, though there has been a paucity of research directly concerned with demonstrating that such control exists (cf. Grice, 1965). There is evidence that on some mixed schedules non-reinforced responses

develop stimulus properties (cf., Ferster and Skinner
1957; Kelleher, 1966). Azrin and Holz (1966), for
example, used a mixed CRF extinction schedule in which
every response was reinforced for 20 responses, after
which all responses went unreinforced for 10 min.
This change in the contingencies was not signalled by
any external stimulus. On the first day when extinction
was introduced a large number of unreinforced responses
occurred in the 10-minute period. By the fourth day
only two or three responses were emitted during
extinction. The authors comment:

> The subject had learned that if a single response
> was not followed by food delivery, the additional
> responses would not be followed by food delivery
> either. The food delivery or its absence had
> taken on discriminative control (p.423).

Similar findings have also been reported by Bullock
and Smith (1953).

Another way in which a response may function as a
stimulus is in a response chain, defined as "a sequence
in which each response functions as a discriminative
(or eliciting) stimulus or produces a discriminative
(or eliciting) stimulus (Kelleher, 1966, p.163)". Thus,
responding on FR schedules has sometimes been regarded
as a chained performance in which non-reinforced responses

act as discriminative stimuli for further responses
(Ferster and Skinner, 1957). It is, however, difficult
to demonstrate that responses have this effect. As
Kelleher (1966) remarks:

> Hypothetical response-produced stimuli have enabled
> theorists to provide plausible accounts for many
> characteristics of response sequences, but there
> is no a priori reason for assuming that response
> sequences are response chains (p.163).

The difficulty involved in assigning stimulus
properties to a particular non-reinforced response, and
in comparing the effectiveness of reinforcements and
responses as stimuli, is compounded by the particular
temporal relationships obtaining between these events
on most schedules. This is, perhaps, best exemplified
by performance on random-ratio schedules. On this
schedule the probability of the reinforcer being presented
is the same following any particular response, whether
reinforced or not. While it is true that each reinforced
and non-reinforced response "predicts" the occurrence of
the next reinforcement equally well, it also seems likely
that this equality of prediction may be more real for the
apparatus and the experimenter than for the experimental
subject. Figure 1 shows an idealised performance on a
random-ratio 10 schedule; sequences of reinforced and

Figure 1. Segment of an idealised
performance on a VR 10 schedule of
reinforcement, showing sequences of
reinforced and non-reinforced responses.

TIME

LONG VERTICAL LINES INDICATE REINFORCED RESPONSES

SHORT VERTICAL LINES INDICATE NON—REINFORCED RESPONSES

non-reinforced responses are presented. This shows
that in the great majority of cases, a number of
responses occur, necessarily, between reinforcements;
reinforcements are therefore truly separated in time -
the higher the ratio value the longer the time between
reinforcements. There is thus a basis for the development
of temporal control by the reinforcing stimulus.

Though reinforcement cannot, except in a very few
instances, be immediately preceded by another reinforced
response, almost every reinforcement can be immediately
preceded by a non-reinforced response. A non-reinforced
response can thus set the occasion for immediate
reinforcement in almost every inter-reinforcement interval.

This marked imbalance in the temporal relationships of
reinforced and non-reinforced responses to the next
reinforcement - which occurs on most schedules of
reinforcement - may perhaps account for the longer pauses
following reinforcement on random-ratio schedules than
following non-reinforced responses. However, it makes a
comparison of the stimulus effectiveness of both these
events very difficult and indeed it is not at all clear
that non-reinforced responses function as stimuli on
random-ratio schedules.

These difficulties are greatly reduced on the DRL reinforcement schedule. On DRL a minimum interval (t), which is timed from each reinforced or non-reinforced response, must elapse before the next response can be reinforced. This schedule does not allow non-reinforced responses to occur immediately preceding reinforcement but ensures that a given interval of time will intervene. Thus each response, whether reinforced or non-reinforced, should have the same predictive value for the subject, indicating that at least t sec must elapse before the next response can be reinforced.

For these reasons, it was hoped that some of the problems regarding the stimulus properties of reinforced and non-reinforced responses might be effectively approached within the context of the DRL schedule. Much of the present thesis is concerned with the question of whether reinforced and non-reinforced responses function as stimuli on DRL and if so, how effective each is in maintaining temporal control of responses.

The following chapter is a selective review of research which is concerned with performance on DRL schedules.

CHAPTER 3

DIFFERENTIAL REINFORCEMENT OF LOW RATE:
A SELECTIVE REVIEW

In a differential reinforcement of low rate
schedule a response is reinforced only if a specified
minimum interval (t) has elapsed since the preceding
response. If a response occurs within the t requirement
reinforcement does not occur and timing starts again
from that response. All responses preceded by inter-
response times (IRTs) longer than t are reinforced.
One modification of this schedule is the imposition of
a limited hold (LH) contingency. This contingency

sets an upper limit to the IRTs which will be reinforced.
Thus if LH = 5 sec an IRT will be reinforced only if it
exceeds t but does not exceed t + 5 sec.

In this chapter much of the literature related to
characteristics of performance on DRL and analyses of
the behavioural control it exerts will be considered.
Two comprehensive reviews of research on the DRL schedule
have been published by Harzem (1969) and Kramer and
Rilling (1970). In the following account attention will
be directed primarily at more recent experiments in the
area, with emphasis on the particular issues relevant
to the research problems central to the present thesis.

DEPENDENT VARIABLE MEASURES

The most frequently used measure of performance in
DRL schedules is the relative frequency distribution of
IRTs. These distributions are typically bi-modal (Sidman,
1956; Conrad, Sidman and Herrnstein, 1958; Staddon, 1965).
For example, if the IRTs on a DRL 20-sec schedule are
recorded in class intervals of 2 sec, one mode will
normally occur in the 0-2-sec category, while the second

mode will occur in the region of the shortest reinforced IRT,i.e., at 20 sec. This can be seen in Figure 2 which shows the data from a single rat subject after extended training on a DRL 20-sec schedule. There is a high frequency of IRTs in the shortest category (0-2 sec), a low frequency of intermediate length IRTs, an increase to a peak frequency in the 20-22-sec category and a gradual decline in the frequency of longer IRTs.

Rate of responding is also used as a dependent variable measure and it is systematically related to the schedule parameters. In an early study with rat subjects, Wilson and Keller (1953) reported that rate of bar-pressing decreased as a linear function of the duration of the IRT requirement. This finding has been confirmed in many subsequent experiments (e.g., Zimmerman and Schuster, 1962; Farmer and Schoenfeld, 1964 a; Staddon, 1965). Response rate provides information regarding the mean IRT duration (mean IRT = 1/response rate). Parametric studies of the DRL schedule in both rats and pigeons have shown that the relation between mean IRT and the duration of the DRL requirement is described by a power function (Malott and Cumming, 1964; Staddon, 1965; Catania, 1970; Richardson and Loughead, 1974 b). The mean IRT measure, although useful, does not

Figure 2. A typical relative frequency distribution of IRTs for the rat. Shaded areas of the distribution indicate reinforced IRTs. Data were obtained from a single animal under a DRL 20-sec schedule.
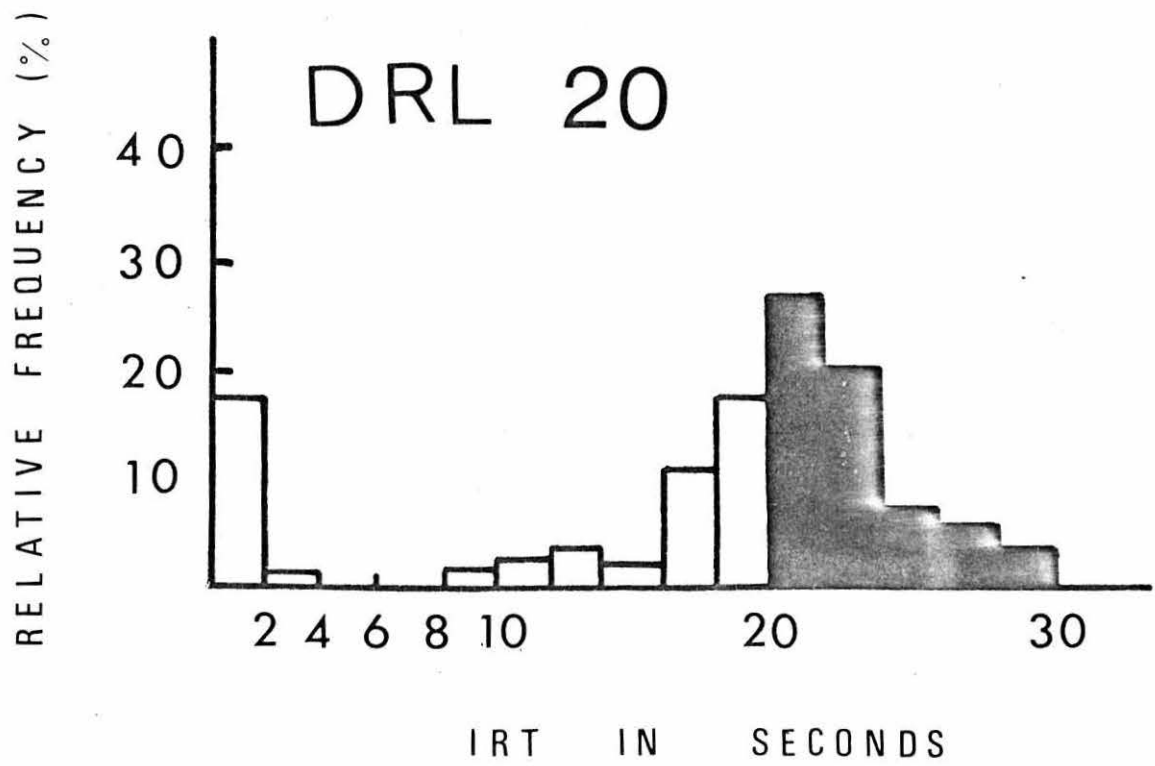
provide an indication of the extent to which it is
representative of individual IRTs. Since the frequency
distribution of IRTs on the DRL schedule is usually
bi-modal, the response rate/mean IRT measure clearly
may not describe the typical IRT occurring in either
of the two modes.

Anger (1956) has recommended the use of the IRTs-
per-opportunity function as a dependent variable on the
DRL schedule. A function describing IRTs-per-opportunity
may be obtained by adjusting the frequency distribution
to make allowance for the fact that in any interval after
a response there are more "opportunities" for short
IRTs than for long IRTs. However, Shimp (1973) has
suggested that frequently there are empirical and
theoretical assumptions underlying the use of this analysis,
which are open to question. For example, Anger (1956)
found a flat IRTs-per-opportunity function early in
training on VI schedules - which is consistent with his
hypothesis that the subject chooses at every brief interval
of time (opportunity) whether or not to respond - and
this experimentation largely provides the empirical
justification for the use of the IRTs-per-opportunity
analysis (Shimp, 1973). A study by Weiss (1970) casts
doubt on the generality of Anger's findings. Weiss found
that the IRTs of monkeys showed a prominent early peak in

the IRTs-per-opportunity function on the first day of
exposure to a DRL 20-sec schedule. This indicates
that the constant function observed by Anger in rats
at the start of VI performance, may not hold for DRL
schedules (Weiss, 1970).

Another measure of responding used frequently on
DRL is the efficiency ratio. This ratio is calculated
by dividing the number of reinforced responses in a
session by the total number of responses, reinforced
and unreinforced, in that session. This provides an
indication of the "correctness" of the animal's
performance; the greater the efficiency ratio, the
fewer the "errors", i.e., unreinforced responses, in a
session. Efficiency in this sense is based on the
number of responses emitted; efficiency might also be
based on time, in which case it would be calculated by
dividing the number of reinforcements obtained by the
overall time spent on the schedule. This measure is
normally labelled "reinforcement rate". Both reinforcement
rate and efficiency, i.e., as related to responses, have
generally been found to be inversely related to the
duration of the schedule requirement (e.g. Wilson and
Keller, 1953; Zimmerman and Schuster, 1962; Smith and
Clark, 1974).

Serial interactions between IRTs have also been
analysed on DRL schedules. Ferraro, Schoenfeld and
Snapper (1965), conducted first order sequential
analyses of IRTs on DRL schedules and reported a
dependency between the duration of a given IRT and the
duration of the preceding IRT. Weiss, Laties, Siegel
and Goldstein (1966) measured serial dependencies
on different DRL schedules and described the pattern
of responding as "...a long wavelength drift
characterised by sequences of reinforced IRTs followed
by sequences of unreinforced - but not particularly
short - IRTs (p.625)".

Together, these measures have provided an extensive
basis for the analysis of performance on DRL schedules.

RESPONSE BURSTS

In accounting for performance on DRL schedules,
authors, for purposes of analysis, have frequently
divided the distribution of IRTs into two sections:
(i) IRTs in the 0-2-sec class interval, and (ii) the
distributions of IRTs around the minimum IRT required

by the schedule. The existence of many short IRTs is
a particularly puzzling feature of responding on DRL
schedules as there are no programmed reinforcement
contingencies for such responses. These IRTs have
been labelled "bursts"; a burst is defined as any
sequence of two or more responses in which no consecutive
responses are separated by more than 2 sec (Kramer and
Rilling, 1970).

Sidman (1956) has observed that bursts occur not
randomly but appear with a high probability after an
IRT which falls just short of the IRT requirement.
Sidman's findings have been confirmed and extended by
Bradley (1971). Using rats as subjects, Bradley conducted
an extensive sequential analysis of responding on DRL
15-sec. He found that burst probability was a direct
function of the duration of the preceding non-reinforced
IRT; no bursts occurred following reinforced responses.
A burst was more likely following a non-reinforced
response and the probability of a burst increased after
a non-reinforced response when the prior run of reinforced
responses was greater than one. The finding that response
bursts occurred only following non-reinforced responses
is consistent with a number of reports (Sidman, 1956;
Carter and Bruno, 1968 a; MacDougall, Van Hoesen and
Mitchell, 1969).

A relationship of another kind between bursts and
the duration of the IRT following a burst, has been
reported. Ferraro et al. (1965) found that the
probability of an IRT which met the DRL criterion was
higher after a burst than after longer, but non-reinforced,
IRTs. Hence, it has been suggested that response bursts
may aid the animal's "timing process" in some way
(Conrad, Sidman and Herrnstein, 1958; Ferraro et al., 1965).
There are other possible explanations for the relationship
observed by Ferraro et al. (1965). If, as Bradley's
(1971) findings indicate, there is a high probability of
a burst following longer non-reinforced IRTs, then there
is bound to be a low probability of reinforced IRTs
following these longer IRTs. Furthermore, after a burst
has occurred only a longer non-reinforced or a reinforced
IRT may then follow. To assess the role of bursts in the
"timing process", a comparison might better be made
between the probability of a reinforced response occurring
(a) after bursts and (b) after single non-reinforced
responses (i.e., responses not in turn followed by a
burst).

Kramer and Rilling (1970) have suggested that bursts
on DRL may be due to a lack of stimulus feedback following
responses. They argue that the pigeon may exert a degree

of force on the response key - or that the rat may
depress the lever some distance - but neither with
sufficient pressure for the response to be registered,
although it may appear "to the subject" to be a
response like any other. These sub-criterion
responses may occasionally precede a response that
produces reinforcement, in which case, the sub-criterion
responses would also be adventitiously reinforced.
Kramer and Rilling have made the point that if stimulus
feedback were presented to indicate when a response
has been made, then the animal's confusion between
responses and sub-criterion responses would be eliminated
and consequently the likelihood of short IRTs would be
diminished. According to this point of view, the
absence of bursts following reinforced responses on DRL
may be due to feedback provided by the delivery of food,
which indicates to the animal that he successfully made
a response.

Recently, the hypothesis that bursts are due to lack
of response feedback has been submitted to direct
experimental test by Flynn, Muirhead and Tedford (1973).
They investigated the effects of stimulus feedback
(i) following reinforced responses and (ii) following all
responses. They used rats as subjects on two DRL schedules,
DRL 10-sec and DRL 15-sec, and presented white noise

lasting 0.5 sec as a feedback stimulus. They found
that the addition of the stimulus to either reinforced
responses or to all responses had no effect on the
occurrence of bursts. Topping and Pickering (1972)
have also found that auditory feedback failed to
produce a decrease in the proportion of bursts emitted
by rats on a DRL 20-sec schedule. Thus, the explanation
of response bursts in terms of deficient stimulus
feedback lacks experimental support.

Staddon (1972) has offered an explanation of bursts
utilising the notion of a "natural" response rate, which,
he maintains, is partly determined for any given
organism by the relative rate of reinforcement: the
higher the rate of reinforcement the higher should be
the natural response rate. Staddon writes as follows:

> One solution to the problem facing the pigeon
> on spaced-responding schedules - that the more
> slowly he responds, and the better he meets
> the spaced-responding requirement, the more
> reinforcement he will receive and thus the more
> difficult it will be to maintain a low response
> rate - is to respond in bursts, with an appropriate
> spacing between bursts. If responses within a
> burst occur at a high rate, the pigeon can begin
> to approach this natural overall rate without a
> substantial drop in reinforcement rate. Thus the
> present account provides an explanation for the
> common, if not universal, finding that animals
> tend to respond in bursts on spaced-responding
> schedules (p.227).

This explanation rests on some untested assumptions, e.g., the notion that there exists a "natural" response rate related to reinforcement rate and that increasing the rate of reinforcement on a DRL schedule makes the animal respond at a faster rate.

Holz, Azrin and Ulrich (1963) investigated the relationship between reinforcement rate and response rate on DRL schedules. They punished all responses of pigeons exposed to a DRL 30-sec schedule with various shock intensities and found a considerable reduction in response rate as a function of shock intensity, with a particularly marked reduction in the frequency of bursts. They supposed that the increase in reinforcement rate produced by the punishment procedure would in turn increase the rate of responding and thus to some extent counteract the suppressive effects of punishment. In the event, they found no evidence for such reinforcement rate effects; the absolute values of punishment intensities used were within the range of intensities necessary to suppress responding on other schedules. They conclude: "It appears that a given punishment intensity remains equally effective regardless of whether the punishment increases or decreases the frequency of reinforcement (p.117)".

According to this evidence, when an animal's behaviour
changes on a DRL schedule in such a way that rate of
reinforcement increases, there is not necessarily a
resultant increase in response rate. This does not
lend support to Staddon's hypothesis regarding bursts.

It has sometimes been considered that response bursts
are not subject to reinforcement manipulations and
are a source of much unsystematic variability (Blough,
1963; 1966; Meltzer and Brahlek, 1967; Schneider and
Neuringer, 1972). However, the study by Holz et al.
(1963) shows that the frequency of bursts can be
reduced if punishment is made contingent upon each
response. In a related study by Bruner (1967), shock
was made contingent only on responses which failed to
meet the DRL requirement. The behavioural effects of
this procedure were similar to those reported by Holz
et al. (1963) for continuous punishment; the proportion
of non-criterion IRTs, particularly bursts, decreased
while there was a corresponding increase in longer IRTs
and in the rate of reinforcement. These punishment
experiments had in common also the feature that when
punishment was removed response rate and consequently
reinforcement rate returned to their former levels.

A more selective application of punishment to
response bursts was attempted by Topping and Pickering
(1972) who made shock contingent upon either of two
"bands" of non-criterion IRTs on a DRL 20-sec schedule:
(i) 0—2-sec IRTs and (ii) 2—20-sec IRTs. Results
indicated that shock effectively reduced the proportion
of bursts which occurred in each session but the degree
of reduction in bursts was the same when either IRT
band was punished.

Time out has been used as a punisher by Kramer and
Rilling (1969) on DRL 20-sec and DRL 30-sec schedules.
Pigeons' responses which failed to meet the DRL
requirement were followed by TOs of different durations
i.e., 5, 10 or 20 sec; TO consisted of a period of
complete darkness in the experimental chamber, where
both the house and key lights were turned out. TOs
of all durations produced similar decreases in the
frequency of bursts and other short IRTs, while IRTs
which met the DRL requirement increased in frequency.
It has been thought that the longer IRTs produced by
this procedure was an effect of punishment by time out
(Kramer and Rilling, 1969; 1970), but it has also
been suggested that blackout may have direct suppressive
effects on the responding of pigeons for some time

following its occurrence (Staddon, 1972). It is not clear in Kramer and Rillings' (1969) study which effect of blackout, antecedent or punishing, was operative.

The evidence so far considered, suggests that the incidence of response bursts on DRL may be reduced by punishment. But the factors which maintain bursts on DRL schedules, or increase their frequency of occurrence, are not yet fully understood.

INTER-RESPONSE TIMES GREATER THAN TWO SECONDS

The gradual rise in the IRT distributions to a mode in the region of the minimum reinforced IRT indicates that animals adapt the temporal pattern of their behaviour to the temporal pattern of reinforcement (Figure 2). Sidman (1956) has noted that the decline in relative frequency of IRTs on either side of this mode resembles a generalisation gradient. The gradient of IRTs below the minimum reinforced IRT class is consistent with this idea, though as Sidman has indicated, the

decline in frequency of IRTs of longer duration, cannot
be attributed to generalisation as all such IRTs are
reinforced. There is also the problem of what it is
that is discriminated or generalised in this situation
(cf. Anger, 1963; Harzem, 1969).

As was found to be the case with bursts, reinforced
IRTs do not occur at random in the course of an
experimental session. Investigators have consistently
reported that there is a higher probability of a
response which follows reinforcement being reinforced
than there is for a response which follows a non-reinforced
response (Skinner and Morse, 1958; Kelleher, Fry and
Cook, 1959; Farmer and Schoenfeld, 1964 a; 1964 b;
Ferraro et al. 1965; Weiss et al. 1966; Carter and
Bruno, 1968 a; Weiss, 1970). The typical finding in
these studies is that performance is characterised by
sequences of reinforced IRTs followed by sequences of
non-reinforced IRTs. According to Weiss et al. (1966),
these sequential relationships may be based on overt
chains of behaviour which occur between reinforcements
and thus help to "mediate" the interval. For example,
if the duration of a chain of behaviour which follows
a reinforced response is as long as the criterion IRT,
then the operant response which terminates the chain will

be reinforced. The collateral behaviour is then
reinforced "superstitiously" so that it comes to
regulate the operant responses in time. However,
like all superstitious behaviour this mediating
response chain may drift out of phase, thus resulting
in IRTs which fall short of the IRT criterion.

The role of such collateral behaviour in the
regulation of temporally spaced responding has been the
subject of considerable experimental investigation. The
occurrence of fairly stereotyped collateral behaviour in
DRL performance has been observed (Wilson and Keller,
1953; Segal and Holloway, 1963; Mechner and Latranyi,
1963; Holz et al., 1963; Nevin and Berryman, 1963;
Laties, Weiss, Clark and Reynolds, 1965; Blackman,
1968; Laties, Weiss and Weiss, 1969; Schwartz and
Williams, 1971). Whether the temporal spacing of responses
is facilitated in some way by the regular sequences of
collateral behaviour which precede responses, is however,
difficult to establish. Accurate timing behaviour on
DRL has been reported to occur in the absence of any
noticeable stereotyped behaviour between responses (Anger,
1956; Kelleher et al., 1959; Reynolds and Catania, 1962;
Belleville, Rohles, Grunzke, and Clark, 1963). Weiss
(1970) has tried to account for the absence of reported

collateral behaviour in these studies by suggesting
that a chain of collateral responding may occur not
just between two operant responses, but may extend,
perhaps, over five IRTs incorporating lever presses
into the chain and thus producing sequences of
reinforced IRTs. He rightly points out that such
chains would be very difficult for an experimenter to
detect.

A number of experiments have shown that, in
those cases where a stereotyped behaviour pattern has
been observed between responses, disruption of the
collateral behaviour has led to a disruption of
established timing behaviour. For example, Laties
et al. (1965) reported an experiment in which a rat
was found to be nibbling its tail in the intervals
between bar-presses on DRL. When the rat's tail was
painted with cycloheximide (an unpleasant tasting
fungicide) the frequency of tail-nibbling decreased and
the shape of the IRT distribution also changed, the
peak shifting slightly toward shorter IRTs. Glazer
and Singh (1971) found that the extent to which IRTs
matched the requirements of a DRL 10-sec schedule was
related to the degree of restraint in three groups of
rats, that were either (i) unrestrained, (ii) partially
restrained, or (iii) severely restrained. They reported

that when unrestrained rats were switched to the
severely restrained condition there was a decrement
in DRL performance, i.e., a reduction in the duration
of IRTs and a lower frequency of reinforcement.

Similar effects of restraint on DRL performance
in pigeons have been observed by Richardson and
Loughead (1974 a) but only when the minimum IRT
requirement was relatively long, i.e., 10 to 15 sec.
Frank and Staddon (1974) found that when pigeons had
been trained in an unrestrained condition on either
DRL 10-sec or DRL 15-sec and then placed in a
restraining tube, performance was disrupted. However,
they also reported that (i) when two groups of pigeons
were trained in restrained and unrestrained conditions
respectively, there was little difference between the
groups in performance on the DRL schedules, and (ii) when
restrained subjects were shifted to an unrestrained
condition there was a substantial disruption of
performance.

In view of this evidence, how is the relationship
between collateral behaviour and the spacing of responses
in time to be regarded? If collateral behaviour serves
as a chain in which the operant response is the final
link, i.e., if the preceding collateral behaviour serves

as a stimulus controlling the DRL response (cf.
Ferster and Skinner, 1957), then disrupting the chain
should remove the stimulus and the responses should not
occur. In fact, when collateral behaviour is disrupted,
the result, in all the studies considered so far, has
been that IRTs became shorter. This indicates that the
stereotyped activities which precede DRL responses do
not serve as stimuli controlling those responses
(Staddon, 1974 b).

An alternative explanation for the disruptive
effects on performance when collateral behaviour is
prevented may be that when a rat's tail is painted
with cycloheximide (Laties et al., 1965) or the
subject is placed in a restraining device (Glazer and
Singh, 1971; Richardson and Loughead, 1974 a; Frank
and Staddon, 1974), a novel element is introduced into
the stimulus environment (Willoughby, 1972) - a
manipulation which is known to have a rate enhancing
effect on DRL responding (Contrucci, Hothersall and
Wickens, 1971; Davis and Iriye, 1973; see below). This
would also account for the fact that when pigeons are
transferred from a restrained condition to one of little
restraint (a novel condition to the animal), responding
is disrupted (Frank and Staddon, 1974). This explanation receives

further support from the finding that when collateral
behaviour is disrupted the deterioration in DRL
performance is often only temporary (Laties et al., 1965;
Frank and Staddon, 1974). The transient nature of
these deteriorative effects also suggests that no
particular pattern of collateral behaviour is necessary
for DRL performance.

Nevertheless, long-term effects of restraint ,
e.g., in between-groups experiments (Glazer and Singh,
1971; Richardson and Loughead, 1974 a), remain to be
accounted for. Anger (1956) put forward the view that
collateral behaviour may serve the purpose of keeping
the animal away from the response lever for a period
of time, by competing with the DRL response. Extending
this notion, Schwartz and Williams (1971) have argued
that the relatively poor performance of pigeons on
DRL schedules in comparison with rats and monkeys,
arises because the DRL situation for pigeons normally
presents little opportunity for the development of
behaviours which can compete with the DRL response. They
found that when they presented an extra lighted key in
the experimental chamber, a substantial number of
responses were directed at this second key in the
intervals between responses on the DRL key; the
percentage of correct DRL responses rose substantially.

Responding on a second response-key which had no
scheduled consequences was also reported by Zuriff
(1969) for pigeons on DRL schedules. He found that as
the DRL requirement was increased the mean time per
run and number of responses in a run of collateral
behaviour on the second key also increased. However,
as the mean IRT on the DRL response-key showed a
much stronger linear relationship with the schedule
requirement than did the measures of collateral behaviour,
Zuriff concluded that the collateral behaviour did not
have a controlling or mediating function in the temporal
spacing of responses on the DRL key.

This conclusion receives support from a study
(Zeiler, 1972) in which two response-keys, in addition
to the reinforced response-key, were available. Responses
to the two additional keys could have either no scheduled
consequences or could reset the DRL schedule timer. If
responses had no scheduled effects on either of the two
keys, the pigeons responded on these keys in the inter-
reinforcement intervals. If responding to both reset the
schedule timer, responding was confined to the DRL key.
Performance on the DRL schedule, however, remained unaffected
by increases or decreases in responding to the other two
response-keys, suggesting that rather than interacting and

affecting each other, responses to the three keys
were independently controlled. A similar independence
of control of collateral responding has been
demonstrated in a two-key experimental situation (McMillan,
1969).

It would appear then, that where the opportunity
for collateral behaviour is present, DRL responding may
be enhanced (e.g., Schwartz and Williams, 1971; Glazer
and Singh, 1971; Richardson and Loughead, 1974 a).
However, collateral behaviour has not been observed in
some studies and when it has been observed, has often
been found not to have a controlling relationship with
performance on the DRL schedule. It may thus be
concluded that the case for collateral behaviour as a
primary determinant of temporally spaced responding has
not been established.

CHARACTERISTICS OF THE RESPONSE

As noted above, it has frequently been observed that the performance of pigeons on DRL schedules is much less efficient than that of other species. For example, Kramer and Rilling (1969) reported that pigeons were approximately 2% efficient on a DRL 20-sec schedule, while Holz et al. (1963) and Staddon (1965) have observed less than 2% efficiency on DRL 30-sec schedules. Comparable efficiency ratios for rats, cats, monkeys and humans are considerably greater (Dews and Morse, 1958; Weiss, 1970; Macar, 1971; Richardson and Loughead, 1974 b).

Nevertheless, in some experimental conditions, pigeons are capable of making accurate discriminations between temporal intervals of different durations (Reynolds and Catania, 1962; Stubbs, 1968). For example, in an experiment by Reynolds (1966), a peck on one key initiated an interval and a peck on a second key terminated it. If the interval between the two responses was greater than 18 sec, further responding on the second key was reinforced on a VI 1-min schedule While the interval between pecks rarely exceeded 18 sec,

the rate of pecking on the second key was an increasing function of the length of the preceding interval. This study suggests that pigeons' behaviour is sensitive to different interval durations but that, at least when the key-peck is the operant, they are unable to withold responding until a time when reinforcement is available.

Most studies of DRL performance in the pigeon have used the key-peck as the reinforced response. Hemmes (1970), on the other hand, employed a treadle response with pigeons as subjects and witnessed 20% to 25% efficiency on DRL 20-sec schedules. This is much better DRL performance than is normally observed when a key-peck response is the operant. Moreover, Hemmes reports that this relatively accurate spaced responding was disrupted in some birds that learned to peck, rather than stand on, the treadle.

These studies, particularly that of Hemmes (1970), support the contention that the key-peck is "...an operant that is not entirely arbitrary... (Schwartz and Williams, 1971, p.160)". It seems likely that the tendency to respond on a schedule of reinforcement may

be stronger or more probable if the operant resembles the consummatory response (i.e., pecking a key, pecking at food) than if the operant is of a different class (i.e., pressing a treadle, pecking at food). The response usually studied in the rat, the lever-press, is different from the consummatory behaviour involved in eating food pellets or licking liquid reinforcers. However, in a study by Kramer and Rodriguez (1971), rats were reinforced on a DRL 10-sec schedule for either of two responses, touching a lever or licking an empty water tube. Water, presented in a dipper, was the reinforcer. Efficiency of responding was found to be considerably lower for the licking response.

The studies described in this section indicate that, at least for rats and pigeons, accuracy of performance is partly determined by the nature of the DRL response.

AMOUNT OF DEPRIVATION

Conrad, Sidman and Herrnstein (1958) found that
the response rates of a monkey and a rat on DRL 20-sec
increased when the food deprivation period was varied
from 0 to 20 hours. Further increases in deprivation
time, from 20 hours to 70 hours, had little effect on
responding.

A two-lever procedure was used in a study by
Mechner and Guevrekian (1962), in which a response on
one lever initiated the DRL interval and a response on
the second lever terminated it. A response on the
second lever was reinforced if the IRT criterion was
met; it not, a response on the first lever re-started
the cycle. Using rats as subjects, they found that the
duration of those IRTs initiated by the first lever
and terminated by the second, remained unaffected by
deprivation levels of from 8 to 56 hours. However, there
were substantial decreases in the duration of the post-
reinforcement pause with increased deprivation, up to
32 hours. Holz and Azrin (1963) and Reynolds (1964 b)
found that progressive satiation of pigeons had little
effect on DRL responding until the subjects reached 95%

of their free-feeding weight.

On the basis of these studies it would appear that DRL responding is not very sensitive to amount of deprivation, except at low levels of deprivation. However, this did not apply to the post-reinforcement pause recorded in Mechner and Guevrekian's study, which showed an orderly change over deprivation periods ranging from 8 to 32 hours.

REINFORCEMENT OF TWO INTER-RESPONSE TIMES

Studies in which two different IRTs have been reinforced in the context of multiple, mixed or concurrent schedules of reinforcement, provide further information regarding the determinants of DRL performance.

A multiple (mult) schedule was employed by Zimmerman and Schuster (1962), in which two different DRL schedules were alternated, each in the presence of a differential stimulus. The minimum IRT requirement in the presence of one stimulus remained constant at 18 sec, while the duration of the IRT requirement during the other stimulus

was either, 36, 54 or 72 sec, for two rats, and 18, 22.5, 27 or 36 sec for the third animal. The results showed frequency distributions for each schedule appropriate to the minimum IRT requirement. In one experimental condition the longer DRL schedule was replaced by a blackout stimulus, during which reinforcement was not presented; the effect of this procedure was to increase response rate on the 18-sec DRL and to shift the mode of the distribution toward shorter IRTs. Zimmerman and Schuster have suggested that this represents an induction effect between both components of the multiple schedule. However, the effects of blackout may well represent behavioural contrast rather than induction; when reinforcement rate and response rate are reduced to zero in one component of a multiple schedule - as happens during the blackout in Zimmerman and Schusters' study - response rate generally increases on the other component (cf. Reynolds, 1961; Reynolds and Catania, 1961; Terrace, 1966; 1968).

Evidence for an induction effect might come from another source. Had the duration of IRTs on the 18-sec component increased as the IRT requirement, and consequently IRT duration, on the other component increased, this would clearly suggest an induction effect. There was little

evidence that this did occur and for one of the three
animals the mode of the DRL 18 distribution shifted
toward shorter IRT intervals as the IRT requirement
of the variable component was increased from 36 to 54 and
72 sec. Again this indicates a contrast effect rather
than induction.

Logan (1967) used a mixed schedule in which two
DRL values alternated randomly, while stimulus
conditions remained constant. Four different pairs
of DRL values were employed: 5 and 30, 10 and 30,
15 and 30, 20 and 30 sec. Three rats were assigned to
each of the four mixed schedules. Once a given IRT
requirement was programmed it had to be satisfied and
reinforcement produced before the next requirement
could come into force. After each reinforcement either
value had the same probability of occurrence. The results
were as follows: (i) on the 5-30 schedule the first
IRT following reinforcement approximated the shorter,
5-sec requirement, while all other IRTs were either
bursts or were in the region of 30 sec, (ii) IRTs after
reinforcement on the 10-30 schedule were either approximate
to 10 sec or 30 sec; other IRTs were again either bursts
or approximated 30 sec, (iii) on the 15-30 and 20-30 schedules

the first IRT after reinforcement approximated the
shorter requirement; other responses showed considerable
variability and included many IRTs below the shorter
criterion, while most were below the longer criterion.

Referring to the shorter IRTs following reinforcement
on all conditions, Logan (1967) has observed that the
prominent mode of adjustment to this type of schedule is
to delay responding for the shortest interval of time for
which reinforcement is ever obtainable. The reinforcer
in this study appeared to function as a discriminative
stimulus which set the occasion for the operation of the
shorter IRT criterion. If reinforcement did not occur
following the first response, then, at least on the 5-30
and 10-30 schedules, the unreinforced response appeared
to serve as a cue indicating that the 30-sec criterion
was in effect. The failure to obtain clear discrimination
of both IRT criteria, particularly on the 15-30, and
20-30 schedules has been attributed to the relative
closeness of the two IRT requirements in these latter
conditions (Logan, 1967; Kramer and Rilling, 1970).

Another possibility could be that the behaviour
shown might be a function of the duration of the shortest
IRT criterion - non-reinforcement can only serve as a cue for

the longer requirement to the extent that the animal
can meet the shorter criterion following reinforcement.
As such efficiency is normally an inverse function of
the duration of the IRT requirement on DRL schedules
(Smith and Clark, 1974), it might be expected that, in
a two-valued DRL as used by Logan, the extent to which
responding will meet both IRT requirements will be a
function of the absolute duration of the shorter
requirement.

The strategy of waiting for the shortest time for
which reinforcement is ever obtainable, based on cues
of reinforced and non-reinforced responses, appears also
to have been adopted by the subjects in a study by
Schoenfeld, Farmer and Vickery (1970). Schedules were
used in which, following reinforcement, there was
either (i) an IRT requirement of 5 sec, or (ii) no IRT
requirement, in which case an immediate response would
be reinforced, i.e., CRF. The probability that the 5-sec
requirement would take effect following any given
reinforcement was varied between zero (conventional
CRF) and unity (conventional DRL). When the probability
of the 5-sec requirement being in effect was low, IRTs
following reinforcement were in the region of 1-2 sec;
following non-reinforced responses either a burst or an

IRT which approximated the 5-sec requirement occurred. As probability approached unity, and the parameters of the schedule approached that of the conventional DRL, longer IRTs were emitted following reinforcement which matched the IRT requirement; the mode at 1-2 sec disappeared.

Schoenfeld et al. (1970) also report a powerful effect of the sequence in which animals were exposed to the various probabilities. Once the animals had been placed on conventional DRL (probability = 1.00), 5-sec IRTs which occurred after reinforcement were much more in evidence on subsequent exposure to the other schedule values than had been the case during first exposure to those values.

Angle (1970) used a mixed schedule with rat subjects, in which two DRL requirements (5 and 15 sec) occurred in fixed-alternation. It was found that if a prior IRT of 5-10 sec was reinforced, then the following IRT was most likely to be 15 sec or greater. If an IRT of 15 sec or more was reinforced the most probable IRT to follow was in the 5-10-sec category. This alternation between IRTs matched that of the programmed contingencies. Following non-reinforced

responses however, there was no correlation between prior and subsequent IRTs. When, in one of the experimental conditions, reinforcement was omitted following the 5-sec IRTs, one of the two subjects responded in a manner similar to that of both subjects on the original mixed schedule. Angle concluded that prior IRT duration may influence the duration of a subsequent IRT but that this relationship is dependent upon the presentation of the reinforcer.

Mallott and Cumming (1964; 1966) reinforced two classes of IRTs within the context of a concurrent schedule; rats' responses were reinforced on a single lever and the probability of reinforcement for different IRT classes was systematically manipulated. The IRT class intervals were specified by their lower bound, the width of each interval being equal to the lower bound. Thus, for example, in the 4-sec — 16-sec schedule only IRTs occurring between either 4-8 sec or 16-32 sec were reinforced. They found (a) that the relative frequency of an IRT occurring in a given class was a function of the relative frequency of reinforcement for that IRT class, (b) when the maximum (programmed) reinforcement rate for the two lower bounds was equal the mode of the IRT distributions generally occurred

in the region of the shortest IRT requirement; this often occurred even when the reinforcement rate was less for the shorter IRT, (c) bi-modal IRT distributions, with each mode occurring around the lower bound of each interval, occurred infrequently; most often at a given reinforcement probability, the animals consistently emitted responses which met one of the two IRT criteria. Malott and Cumming (1966) conclude,"the data clearly support the notion that there was a response bias in favour of short IRTs (p.325)".

Staddon (1968), using a procedure similar to that of Malott and Cumming confirmed their finding of a direct relationship between the relative frequency of an IRT and the relative reinforcement for that IRT. Staddon reported in addition, a greater incidence of bi-modal IRT distributions, occurring in the region of each reinforced IRT class. These findings were further confirmed and extended by Shimp (1968; 1969),who found that, when two different IRTs were reinforced on a one-key concurrent VI VI schedule, the relative frequency of an IRT was approximately equal to the reciprocal of its length, when both IRTs were reinforced equally often. It was also established that the way in which the relative

frequency of an IRT depends on the relative
frequency of reinforcement for that IRT is the same
whether the two IRT classes are reinforced on a
single key or on different keys (Moffitt and Shimp,
1971).

The high incidence of short IRTs has led Shimp
(1968) to conclude that "operants that are more time
consuming (e.g., longer IRTs) require greater payoffs
to be preferred as much as short ones (p.532)". This
indicates a response bias of the sort hypothesised by
Malott and Cumming (1966).

THE ROLE OF THE REINFORCER AS A DISCRIMINATIVE STIMULUS

Evidence for the discriminative function of the
reinforcing stimulus in DRL schedules has already been
encountered in some of the studies discussed above. In
Logan's (1967) experiment the reinforcing stimulus, on
some values of a mixed DRL DRL, was shown to serve as a
discriminative stimulus, controlling IRTs which

approximated the shorter of the two DRL requirements.
When two DRL components are presented in fixed alternation
(Angle, 1970) the reinforcing stimulus appears to be
a necessary factor in controlling the alternation of
IRTs. However, the influence of the reinforcer as a
discriminative stimulus is difficult to determine in
this latter study, as the reinforcer by itself did not
differentiate a particular component (Angle, 1970).

The tendency for reinforced IRTs to follow reinforced
IRTs, while non-reinforced IRTs tend to follow non-
reinforced IRTs, has been attributed to a discriminative
function of the reinforcer. (Farmer and Schoenfeld,
1964 b; Carter and Bruno, 1968 a; 1968 b; MacDougall
et al., 1969; Weiss, 1970). It has been suggested by
these authors, that the reinforcer is a more effective cue
for the initiation of a chain of mediating behaviour than
is a non-reinforced response. As evidence in support of
this hypothesis, Carter and Bruno (1968 a; 1968 b) have
reported that when reinforcement is withheld on DRL,
there is little resistance to extinction, particularly
when DRL behaviour has been well established and the
efficiency ratio exceeds 0.5. It is argued that in
extinction the omission of reinforcement eliminates the
discriminative stimuli for the mediating chain of responding

and, of course, the operant response which terminates
the chain.

In studies where responding on DRL was extinguished
and then reconditioned, reconditioning proceeded rapidly
(Reynolds, 1964 a; 1964 b; Ferraro et al., 1965; Carter
and Bruno, 1968 a; 1968 b). Reynolds (1964 a)
reported full recovery of normal DRL performance after as
few as two reinforcements in reconditioning. He concluded
as follows:

> The rapidity and accuracy of reconditioning
> suggest that the process is in this instance
> related to performance rather than to relearning.
> From the two reinforcements, the bird does not
> relearn the temporal spacing of successive pecks
> that prevailed before extinction any more than
> it relearns to peck. The performance has not
> been lost during extinction, rather it lacks one
> of its conditions of occurrence, the reinforcer.
> The occurrence of the reinforcer reinstates the
> conditions that prevail before extinction, when
> pecking was reinforced and when the bird learned
> to space pecks (Pp.274-275).

According to the mediation hypothesis these reinstated
conditions would include the mediating chain of responses
controlled by the reinforcer.

Some of the difficulties involved in accounting for
DRL performance in terms of mediating chains of behaviour
have been discussed above. It may be added that an

explanation of the finding that reinforcement is a
better initiator of spaced responding than is a
non-reinforced response, stated in terms of reinforcement
providing a better cue for mediating responses, leaves
unresolved the problem of why reinforcement should
provide a better cue for mediating behaviour than
non-reinforced responses.

Farmer and Schoenfeld (1964 b) have suggested that
both reinforcers and non-reinforced responses may
function as discriminative stimuli for the emission of
IRTs meeting the DRL criterion but that the closer
accuracy in timing a DRL interval from reinforcement
may depend on the greater intensity of exteroceptive
cueing which accompanies the latter event. In support
of this hypothesis they report that in their experiment
the auditory stimulation at reinforcement, e.g., made by
movement of the dipper mechanism, exceeded that of the
microswitch sound accompanying a bar press. But this is
not confirmed by Flynn et al.'s (1973) study, in which
an additional auditory stimulus was presented at
reinforcement during some phases of their experiment;
they found that the added stimulus had no effect on
responding.

An alternative possibility is that the greater intensity of stimulation provided at reinforcement might not be due to additional auditory stimuli accompanying reinforcement, but may be a function of stimulation, visual and gustatory, provided by the reinforcer itself. This latter suggestion is supported by a study in which pigeons' key-peck responses on a DRL 20-sec schedule were occasionally followed by presentations of the feeder magazine and associated stimuli for periods of time so brief (0.5 sec) as to preclude the obtaining of any food, a procedure known as "feeder flash" (Miller, McCullough and Thompson, 1970). It was found that IRTs of sufficient duration to satisfy the DRL requirement were more likely to follow responses that produced the feeder flash than to follow responses which did not produce the feeder flash. This evidence suggests that the visual stimulation which occurs at reinforcement may enter into the determination of subsequent IRTs, thus accounting for the difference in the duration of IRTs following reinforced and non-reinforced responses.

INHIBITION IN DRL SCHEDULES

Staddon (1970 b) has indicated that the reinforcing
stimulus in DRL has inhibitory after-effects. Reinforcement
omission studies have lent some support to this
suggestion. In a study by Caplan (1970), rats were
trained on DRL 8-sec and DRL 1.2 -sec schedules, and then
a proportion of reinforcements for "correct" IRTs were
omitted. The probability that a correct IRT would be
reinforced varied from session to session, and ranged
from 1.0 (standard DRL) to 0.2; in place of reinforcement
an auditory stimulus and a visual stimulus were presented.
Response rate decreased - and efficiency increased - as
a function of reinforcement probability. A similar
effect has been reported by Davenport, Flaherty and Dyrud
(1966) who employed a modified DRL procedure (cf. Mechner
and Guevrekian, 1962) with both monkeys and rats.

It has been argued that inhibitory effects may
occur throughout the DRL schedule and not just following
reinforced responses (Hearst, Koresko and Poppen, 1964;
Kramer and Rilling, 1970; Richelle, 1972; Halliday
and Boakes, 1972). Some studies have tested for such
inhibitory effects using disinhibition procedures in which
novel stimuli are presented in the course of the schedule;

if responding is normally inhibited on DRL, then, it
is argued, when a novel stimulus is presented responding
should be disinhibited and should show an increase in
frequency.

In a study by Contrucci et al. (1971), rats were
trained on a DRL 20-sec schedule and during testing a
4-sec buzzer was occasionally presented either 6 or 12
sec after a reinforcement. It was found that the number
of non-criterion responses increased in the inter-
reinforcement intervals during which the buzzer was
presented, as compared with non-criterion responses
occurring in other intervals in which the buzzer was
absent. In this study the novel stimulus was presented
only after a reinforced response. Davis and Iriye (1973),
however, presented a novel stimulus following both
reinforced and non-reinforced responses. Rats were placed
on DRL schedules of either 10, 20 or 30 sec with a tone,
approximately 0.5 sec in duration, occasionally presented
midway in the DRL interval. The durations of IRTs were
found to be shorter following presentations of the tone and
this effect was strongest on the longer DRL values. Davis
and Iriye do not report whether there was any difference
in disinhibition effects in intervals preceded by reinforced
or non-reinforced responses.

Brimer (1972) has provided further evidence of disinhibitory effects of novel stimuli. Using a DRL 120-sec schedule and rats as subjects, he presented a novel stimulus, a light which remained on for 3 min, at one of two fixed times, either 26 or 51 minutes after the start of a session. The other 3-minute test period was a "dummy" presentation, i.e., the light stimulus was not presented but response data were recorded for comparison with data taken from the 3 min during which the light was on. Subjects had significantly higher response rates during the stimulus than during dummy intervals.

Evidence of another kind for the existence of inhibitory effects comes from studies in which generalisation testing has been conducted with stimuli associated with DRL schedules. For example, in a study by Hearst et al. (1964), generalisation gradients were obtained from pigeons that had been trained on VI and DRL schedules. In these schedules 30-sec periods, during which a line stimulus was projected onto the response key, alternated with 10-sec periods of blackout. For the VI subjects, a VI 1-min schedule was in effect during stimulus-on periods, while for DRL subjects either

DRL 6-sec or DRL 10-sec schedules were operative
during the line stimulus. In test sessions
reinforcement was withheld and generalisation
gradients were obtained along the line-tilt continuum.
Gradients following training on VI were sharply peaked
at the training stimulus, a finding which replicates
that of Guttman (1959). The generalisation gradients
produced by the DRL animals, however, were relatively
flat and few showed any gradient peak at the training
stimulus. To account for these findings Hearst et al.
suggested that DRL may possess aversive or inhibitory
effects which in combination with positive properties
of the schedule, produce unexpected effects on stimulus
generalisation.

An experiment by Weisman (1969) bears upon this
speculation. A DRL schedule in which the IRT
requirement was gradually increased to either 16 sec or
20 sec, was used to gradually decrease the response rate
in one component of a mult VI 1-min VI 1-min schedule,
without also decreasing reinforcement rate. A
generalisation test along the stimulus dimension associated
with the DRL schedule yielded a U-shaped gradient of
inhibitory stimulus control.

The experiments of Weisman (1969) and Hearst et al.
(1964) differ in some respects: the DRL schedule was

alternated with a VI 1-min schedule in Weisman's experiment,
with a blackout period in the Hearst study. The minimum
IRT criterion used by Weisman was also of longer duration.
Such factors may account for the stronger inhibitory
effects reported in the latter study. For example, the
inhibitory or aversive properties of a DRL schedule may
be enhanced (i) when contrasted with another schedule of
positive reinforcement which maintains a high response
rate (Terrace, 1966), and (ii) when a long DRL value is
used (Kramer and Rilling, 1970).

Kramer and Rilling (1970) and Richelle (1972) have
proposed that, as inhibitory control normally has aversive
effects, investigators who seek to establish its
existence on DRL should look for aversive properties of
the schedule. Since schedule-induced aggression is
considered to be a product of aversive contingencies
(cf. Chapter 2), its existence would provide indirect
evidence for inhibitory control. Furthermore, as the
studies discussed above indicate that inhibitory effects
on DRL are not limited to the period of time following
reinforcement, then schedule-induced aggression presumably
should not be confined to the post-reinforcement period
but should occur throughout the schedule. This was found
to be the case by Knutson and Kleinknecht (1970). Pigeons

exposed to a CRF schedule and a DRL 20-sec schedule
attacked a restrained target during DRL 20-sec but not
during CRF. Attacks were distributed throughout the
entire session on the DRL schedule. This is in marked
contrast with the findings on FI, FR, VI and VR schedules
in which aggression occurs predominantly during the
post-reinforcement pause (Gentry, 1968; Richards and
Rilling, 1972; Dove et al. 1974; Webbe et al., 1974).

The evidence presented indicates that inhibitory
effects are fairly widespread on DRL schedules. How may
this be explained? One possibility is that both reinforced
and non-reinforced responses may function as inhibitory
stimuli on DRL. Both of these events set the occasion
for a period of non-reinforcement - equal to the duration
of the IRT requirement - and, in comparison with the
control exerted by the reinforcer on FI (cf. Chapter 2),
they might thus be expected to inhibit responding for a
period of time, so that responses occur in the last half
or third of the interval. Responses are not, however,
most frequent midway, or even two-thirds of the way,
through the DRL criterion interval but tend to occur later,
matching the criterion IRT. This indicates stronger
inhibitory control of responding on DRL than exists on other
comparable interval schedules.

Davis and Iriye (1973) have argued that responses
which fail to meet the minimum IRT requirement are
systematically punished by the delay of reinforcement
which is a consequence of these responses. If such
responses go not only unreinforced but are also punished -
and given that many non-reinforced responses occur on most
DRL schedules - this would clearly provide a basis for
stimulus events in the DRL schedule acquiring strong
inhibitory control.

Data reported by Richardson (1973) indicate that
apart from the effect of reinforcement rate or the
distribution of inter-reinforcement intervals, there
are additional suppressive effects operating on the DRL
schedule. A yoked control design was used to compare
the performance of animals on a DRL 15-sec schedule
with that of animals on a VI schedule in which the
programmed inter-reinforcement intervals were the same
as the inter-reinforcement intervals of the "lead" DRL
subjects. Though reinforcement rates were equated for
both groups of animals, response rates on the DRL
schedule were significantly lower than on the VI schedule.

One standard procedure for testing whether a given
consequence of behaviour is a punisher is to vary its
dimensions and observe the extent to which it reduces

response frequency, e.g., electric shock (Azrin and Holz, 1966). A direct test of punishment effects on DRL, might thus involve increasing the duration of the reinforcement delay contingency, i.e., the minimum IRT requirement on a conventional DRL schedule. It has frequently been shown that as the DRL requirement is increased response rate decreases. However, a little can be deduced from this finding with regard to punishing effects, since increasing the DRL criterion also decreases the rate of reinforcement and this latter effect may be responsible for a reduction in response rate (cf. Staddon, 1972). In order to directly test the punishment hypothesis it would be necessary to vary the duration of the delay following responses, without reducing the frequency of reinforcement for those responses.

The occurrence of bursts may also be related to the aversive consequences of non-reinforced responses on DRL. A number of authors have indicated that the unconditioned response to omission of reinforcement, following regular reinforcement, is heightened "emotionality", "aggression" or "frustration" (Skinner 1938; Mower and Jones, 1943; Keller and Schoenfeld, 1950; Amsel, 1958; 1962; Leitenberg, 1966), thus

accounting for the common finding that with the onset
of extinction following regular reinforcement there is
an increase in the rate of responding.

On the DRL schedule some responses (*i.e.*, those
meeting the criterion) are reinforced and some go
unreinforced. If the latter are regarded as instances
of reinforcement omission then response bursts might be
a function of (i) the aversive or emotional effects of
non-reinforcement and/or (ii) the aversive effect of
the reinforcement delay initiated by the non-reinforced
response.

The effect of the duration of reinforcement delay
on frequency of bursts might be investigated by observing
burst frequency at different DRL values. Richardson and
Loughead (1974 b), for example, found that there was some
tendency in pigeons for the proportion of bursts to
increase as the IRT requirement was increased, though the
frequency of bursts in rats remained unaffected by schedule
value. However, as has already been noted, increasing the
DRL criterion decreases the frequency of reinforcement.
This in itself might be expected to increase the proportion
of bursts in a session, as bursts are more frequent following

non-reinforced responses (Bradley, 1971). Any increase in bursts cannot, on the basis of these data, be attributed to the aversive effects of increased reinforcement delay.

The role of the delay contingency as a determinant of responding on DRL schedules will be investigated in experiments described in the following chapters.

CHAPTER 4

EXPERIMENTAL METHOD

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

SUBJECTS

Male albino rats were used as subjects in all experiments. They were housed individually and water was freely available in the home cages. The lights in the room which held the home cages were on from 7 a.m. to 8 p.m. each day. The room temperature was kept at approximately $20^{o}C$.

Deprivation

The animals were weighed daily at the same time.
Free-feeding weight was calculated over a period of
7 days on ad lib access to food, immediately before
the commencement of a deprivation regime. Subsequently,
the weight was maintained at approximately 80% of the
free-feeding weight. Maintenance of body weight and
changes in body weight were achieved by feeding varying
amounts of food once per day, an hour after the end of
experimental sessions.

APPARATUS

Three identical operant conditioning boxes were
used. Each box had a floor area of 20.0 cm x 24.0 cm
and its height was 18.5 cm (inside measurements). Three
of the walls were made of bakelite, lined on the inside
with sanded plate aluminium; the fourth, a 20 cm wide
wall, was a metal panel on which the lever and the
reinforcement mechanism were mounted. A recess, 4.0 cm
wide, 5.0 cm high and 5.0 cm deep, was located in the
centre of this panel. The floor of the recess was level
with the floor of the box. The reinforcer, 0.05 ml of
a solution of Nestle's condensed milk in water, was
delivered up to the floor of the recess by a motor-

operated dipper mechanism. The dipper was normally
"up"; at reinforcement it was depressed into the
container placed below it and then returned to the
resting position.

A lever was mounted 7 cm to the left of the recess,
and 4.7 cm above the floor. It was 5.0 cm wide and
protruded 1.5 cm into the box. The minimum downward
pressure required to depress the lever was set at
10 gm. Two circular lights were also mounted on either
side of the panel 14.0 cm from the floor.

The floor of the box was made of cylindrical metal
bars, each with a diameter of 0.8 cm; they were spaced
equidistantly and parallel to the panel. The roof of
the box was a perspex lid held in position by two folding
flaps. Each box was housed in a sound attenuating
chamber, containing a 3-w light located on the ceiling,
and an exhaust fan mounted on one side, producing
ambient noise at 60 ± 2 db.

Auditory stimuli were programmed by feeding a
100 Hz square-wave tone to a 3-stage 3 watt amplifier.
The output was fed to an 8 inch 3 ohm speaker mounted on

the inside of the door of the chamber. This signal
was attenuated by a series of switchback potential
divides, whose resistor values gave an output of 75 db.
Sound intensity levels were measured by a Dawe sound-
level meter with a reference level of 0.0002 dyn/cm
at 1000 Hz.

To facilitate within-sessions changes in the
concentration of the reinforcer (Experiments 7-9) four
containers were mounted on a circular aluminium plate,
the centre of which was bolted to the spindle of a 24V
AC motor/gearbox. This was situated below the dipper
mechanism and the container into which the dipper
descended could be changed by operating the motor via
external programming equipment.

Programming and recording were controlled by solid-
state logic units mounted on a bus-bar rack system and
housed in a separate room. Responses and reinforcements
were recorded on (i) Gerbrands cumulative recorders,
(ii) Sodeco counters, (iii) a Kienzle digital print-out
counter, programmed to print out the duration of each
IRT in 0.1 sec units.

GENERAL PROCEDURE

Each animal was first trained to approach the reinforcement mechanism and to take the reinforcer. After this, lever-pressing behaviour was shaped by the method of successive approximation (Skinner, 1953 b). Sessions were conducted daily and lasted 1 hour (with the exception of Experiment 2, in which sessions lasted 40 min). The reinforcer in Experiments 1-5 was a 30% solution of condensed milk in water; reinforcer concentrations in Experiments 6-9 are specified separately for each experiment.

Stability Criteria: In the present study three criteria have been used in the determination of stable schedule performance: (i) visual inspection of IRT frequency distributions and cumulative records, (ii) number of sessions exposure to a given schedule, (iii) the response rate on each of six successive sessions was compared with the response rate across these 6 sessions; a difference of less than 10% was judged to indicate stable performance (the formal criterion).

These criteria were used in all the experiments, in appropriate combinations. In each experiment the criteria used to determine stability will be specified.

CHAPTER 5

TWO-COMPONENT DRL SCHEDULES OF REINFORCEMENT

The regular spacing of responses in time, which
is characteristic of performance in DRL schedules,
suggests that each response may serve as a stimulus for
the response which follows it. There is however, a
difficulty here, expressed by Staddon (1972) as follows:

>...on spaced responding schedules (DRL) temporal
control of each response by the preceding response
may be inferred - although in this case control
(as distinct from mere temporal regularity) is
hard to demonstrate, because responses cannot be
directly manipulated by the experimenter (p.213).

There is also the question of the stimulus properties of
the reinforcer. Several authors have argued that the
reinforcer has discriminative effects on the DRL schedule,
which result in more accurate responding following the
reinforcer than following non-reinforced responses
(e.g., Farmer and Schoenfeld, 1964 b; Carter and Bruno,
1968 a; 1968 b; Weiss, 1970). If the spacing of
responses in accordance with the requirements of the
schedule is a function of discriminative control by prior
responses and reinforcements how may the high frequency
of those responses which fall far short of the minimum
IRT requirement and are never reinforced, i.e., response
bursts, be explained?

As Staddon (1972) has indicated, the controlling
relationships are difficult to establish on conventional
DRL schedules. In the DRL schedule, two contingencies
operate concurrently: (i) responses which meet the IRT
criterion are reinforced, while those which do not meet
the criterion go unreinforced, (ii) following a response
the availability of reinforcement is delayed for a period
of time equal to the duration of the minimum IRT
requirement. As the duration of the delay contingency is
the same after reinforced responses (i.e., responses
meeting the DRL requirement) as after non-reinforced

responses (i.e., responses falling short of the requirement), it is difficult to determine whether each of those events separately maintain temporal control of the responses which follow them.

In the present study a two-component DRL schedule was devised, which specified separately the minimum IRT criterion for (i) IRTs initiated by reinforced responses, and (ii) IRTs initiated by non-reinforced responses, thus making possible an assessment of the stimulus properties of reinforced and non-reinforced responses in controlling IRTs of different durations. The basic schedule consisted of two separate contingencies: (i) if a reinforced response initiated an IRT, the response that terminated that IRT was reinforced only if it exceeded a specified minimum duration, t_1 (This is termed the "t_1 requirement"). (ii) if the response terminated an IRT shorter than t_1, that response was not reinforced, and it initiated a different IRT criterion, t_2, which specified separately the duration of the minimum IRT required for reinforcement (This is termed the "t_2 requirement"). The t_2 requirement remained in effect until a response met the t_2 reinforcement criterion. At reinforcement the contingency switched back to t_1.

Davis and Iriye (1973) suggested that, on the conventional DRL schedule, the delay of reinforcement, which is a consequence of responses which fail to meet the minimum IRT requirement, serves as a punisher for these responses and this results in the low response rate characteristic of DRL schedules. One way of testing their hypothesis is to manipulate this variable; response rate should decline as a direct function of the IRT requirement (cf., Wilson and Keller, 1953). However, increasing the duration of the DRL criterion will also result in a decrease in the rate of reinforcement obtained by the subject, which may in itself have depressive effects on the rate of responding (Staddon, 1972).

In the two-component DRL schedules to be reported, the duration of the IRT requirement in the t_1 component* was held constant while the duration of the requirement in the t_2 component was systematically varied. This allowed the reinforcement contingency to remain the same for "correct" responses in the t_1 component while altering the delay of reinforcement availability as a consequence of responses which failed to meet the t_1

* Components are identified by the IRT requirement in operation.

criterion. This manipulation also made possible an assessment of the effect of the delay contingency on the frequency of response bursts on DRL schedules.

EXPERIMENT 1

Subjects

Four experimentally naive male albino rats (103, 105, 106 and 107), 90 days old at the start of the experiment, served as subjects.

Procedure

Following lever-training each animal was placed on one of the two-component schedules in daily 1-hour sessions. In every case t_1 was held constant at 20 sec and t_2 was changed after reaching response stability with a given t_2 value. In the DRL 20-10 schedule, for example, the IRT requirement in operation after reinforced responses, i.e., on the t_1 component, was 20 sec. When a response failed to meet the 20-sec criterion, the t_2 requirement of 10 sec came into operation. This remained in effect until an IRT exceeding 10 sec occurred, whereupon the reinforcer was presented and the t_1 component was reinstated.

For two of the animals the initial t_2 requirement
was 20 sec; the schedule was thus the conventional
DRL 20-sec, though expressed here as DRL 20-20. One of
the two subjects was then exposed to a higher t_2 value
of 30 sec while t_2 was reduced to 10 sec for the other.
Both animals were finally placed on a t_2 value of 60 sec.
The remaining two animals were initially placed on DRL
20-30 and then t_2 was reduced for one to 10 sec and for
the other increased to 40 sec. The values of t_2 used,
the sequence in which each animal was exposed to different
schedule values and the number of sessions on each schedule
are shown in Table 1.

According to the formal criterion of stability, which
was met when response rate on any one session in a block
of six successive sessions did not differ by more than 10%
from the mean response rate for that block, responding
became stable within about the first 30 sessions on each
schedule. Approximately 60 sessions were conducted on
each schedule, however, since no previous information was
available on schedules of this kind and it was not known
whether further changes would occur after responding
reached initial stability. No such changes were observed.
Following 60 sessions exposure to each schedule, the

Table 1

Order of exposure to the schedules (listed top
to bottom) and the number of daily 1-hr sessions
on each schedule, for individual subjects.

Subject	Schedule Parameters t_1-t_2(sec)	Number of Sessions
	DRL 20-20	65
106	DRL 20-10	63
	DRL 20-60	65
	DRL 20-20	65
107	DRL 20-30	63
	DRL 20-60	67
103	DRL 20-30	63
	DRL 20-10	65
	DRL 20-30	64
105	DRL 20-40	65

duration of t_2 was altered when the formal stability criterion and visual inspection of the records showed that responding was stable.

Results

The relative frequency distributions of IRTs for the t_1 and t_2 components, obtained in the last two sessions of each condition with each subject, are shown in Figures 3 and 4. Corresponding overall frequency distributions for all the IRTs in the session regardless of components are presented in the Appendix. (Figures 55, 56, 57, 58). In all cases IRT distributions on t_1 had a single mode and that was in the region of the earliest IRT interval in which reinforcement could occur, i.e., 20 sec. Bursts did not occur on t_1. As the duration of the t_2 requirement was increased, proportionally fewer IRTs on the t_1 component were short of the 20-sec criterion.

Relative frequency distributions on t_2 were bi-modal with one mode occurring in the shortest IRT interval. The second mode was frequently in the region of the minimum IRT requirement in t_2; as the duration of the IRT requirement in t_2 increased, the mode shifted toward longer IRTs, though becoming flatter on the longer t_2 values.

Figure 3. The relative frequency
distributions of IRTs for Animals
106 and 107 on each schedule. The
frequencies are shown separately for
the t_1 (left column) and t_2 (right
column) components. In the t_2 distribution
IRTs longer than 80 sec are contained
in the final IRT category. The shaded
areas of the distributions indicate
reinforced IRTs. Data are from the last
two sessions on each schedule.

ANIMAL 106

20-10

20-20

20-60

ANIMAL 107

20-20

20-30

20-60

RELATIVE FREQUENCY (%)

IRT IN SECONDS
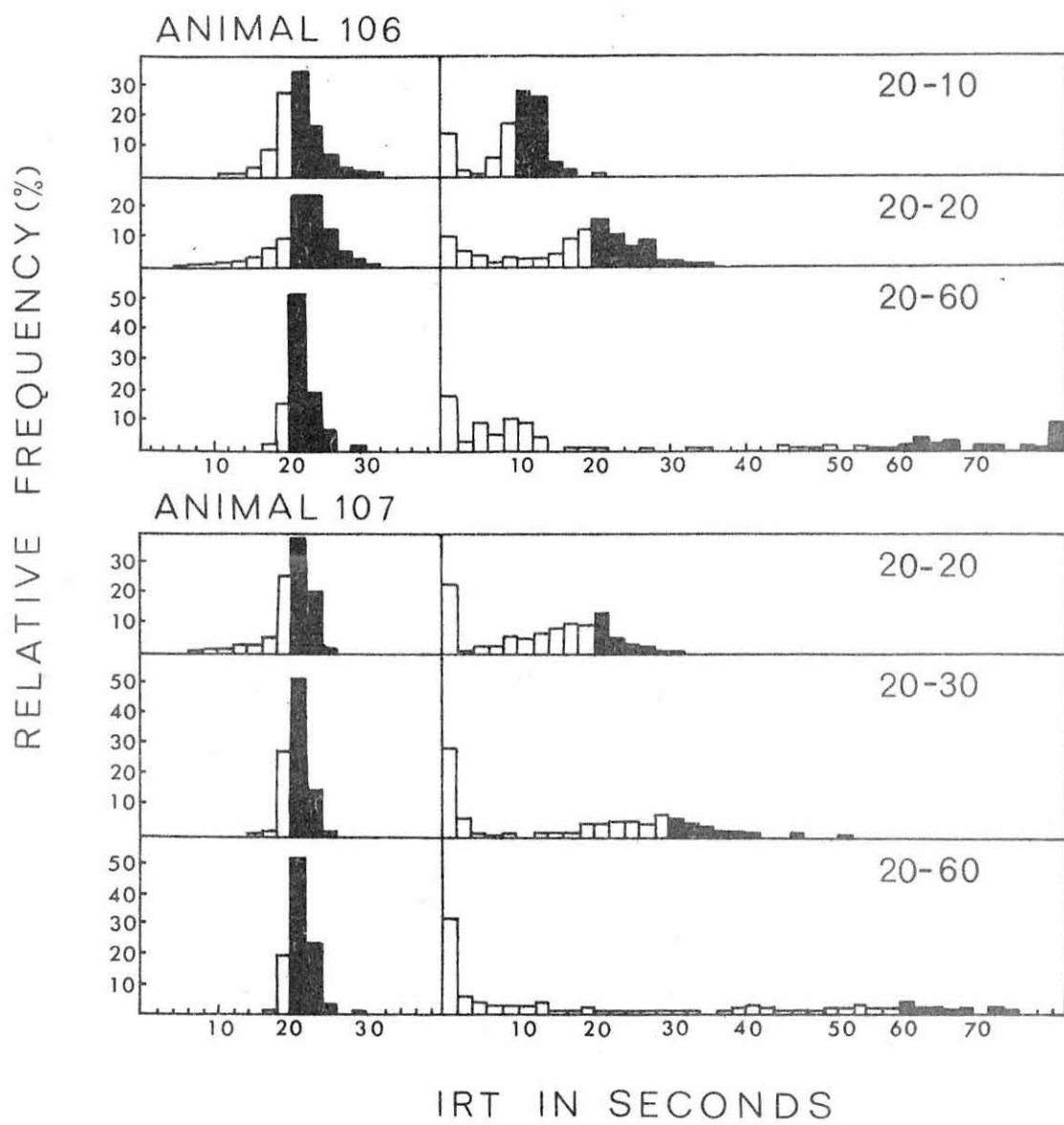
Figure 4. The relative frequency
distributions of IRTs for Animals
103 and 105 on each schedule. The
frequencies are shown separately
for the two components of the
schedules. The data are from the
last two sessions on each schedule.

ANIMAL 103

ANIMAL 105

RELATIVE   FREQUENCY (%)

IRT   IN   SECONDS
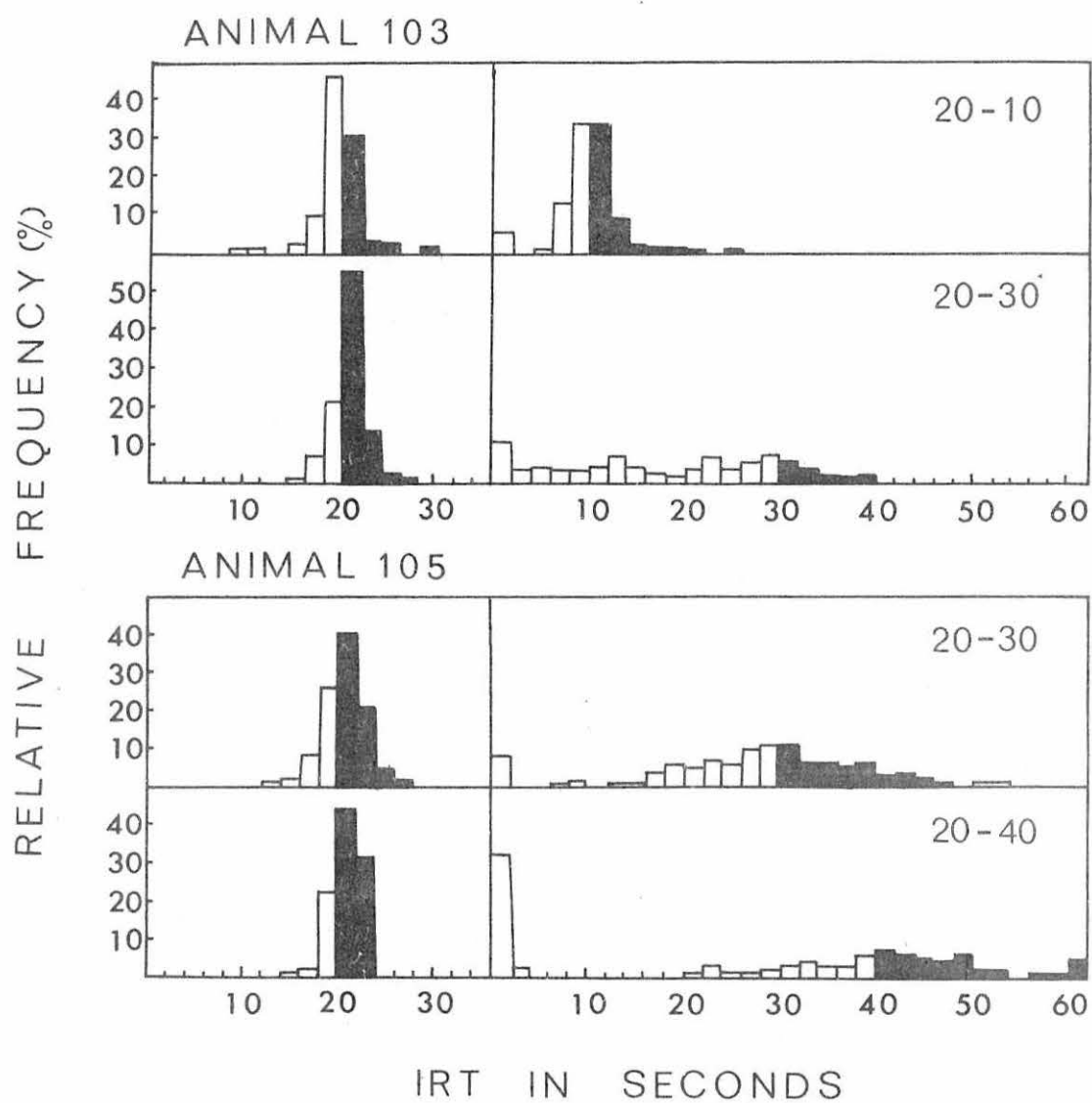
Figure 5 shows that responding on both components was appropriate to the specific DRL contingencies. In this figure, sequences of IRTs which occurred when the contingency switched from t_1 to t_2 are shown. The data are from the last four occasions when such a sequence occurred in the final session of each schedule. In the top left section of Figure 5, for example, the first IRT shown for Animal 106 on DRL 20-10 exceeded 20 sec and was thus reinforced (filled circle). This put the t_1 contingency into effect. The next IRT, though close to the 20-sec requirement, fell just short of it and was not reinforced (open circle). This put the 10-sec requirement of t_2 into effect. The next IRT in this case just exceeded the 10-sec requirement. (In the other sequences a very short IRT, a burst, sometimes occurred following the first non-reinforced IRT.) Reinforcement was presented and t_1 initiated again. The t_1 criterion of 20 sec was met by the next two IRTs.

The performance of the same animal on DRL 20-60 shows similar control by the two contingencies. Following reinforcement, i.e., in the t_1 component, IRTs were approximately 20 sec whereas following non-reinforced responses IRTs were either of short duration or exceeded the t_2 criterion of 60 sec. Control on the t_2 component in

Figure 5. Sequences of IRTs from each
animal which show transitions from the
t_1 to the t_2 contingency and the return
to the t_1 contingency, plus two
subsequent IRTs. For each schedule the
last four such sequences in the last
session are shown. Filled circles indicate
IRTs which were reinforced. Open circles
indicate non-reinforced IRTs.
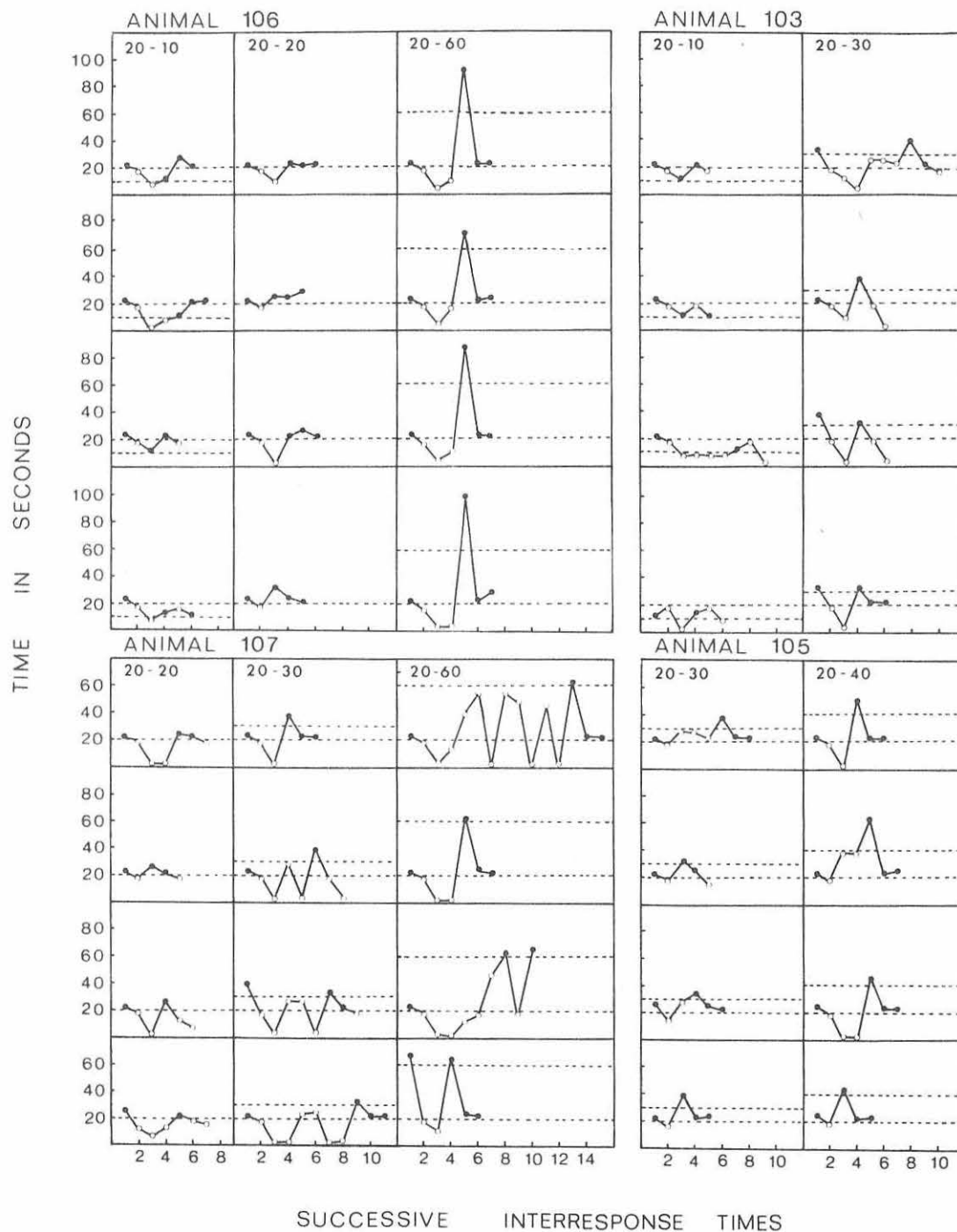
the DRL 20-60 schedule was considerably less precise
than with the shorter t_2 requirement of the DRL 20-10
schedule. These relationships were also observed in
the results of other subjects, with different values
of t_2 (Figure 5).

Figure 6 shows that, for each subject, the median
IRT on the t_1 component was an increasing function of
the t_2 criterion. These data are consistent with the
relationships observed in Figures 3 and 4, where it was
shown that IRTs on the t_1 component which fell short
of the minimum requirement declined in frequency as t_2
increased.

Median IRTs have not been presented for t_2
distributions in Figure 6 as these distributions were
bi-modal; the median would thus not be representative
of either mode. A similar difficulty exists for the
response rate measure, presented in Table 2. This shows
that for all animals, rate of responding in the t_2
component declined as the IRT requirement was lengthened.
Decreases are also evident in overall response rates
and, to a much lesser extent, in response rates on the
t_1 component, as a function of t_2 duration.

Figure 6. The median and interquartile range of IRTs on the t_1 component, as a function of the minimum IRT criterion on the t_2 component. Data are from the last two sessions on each schedule, for each subject.
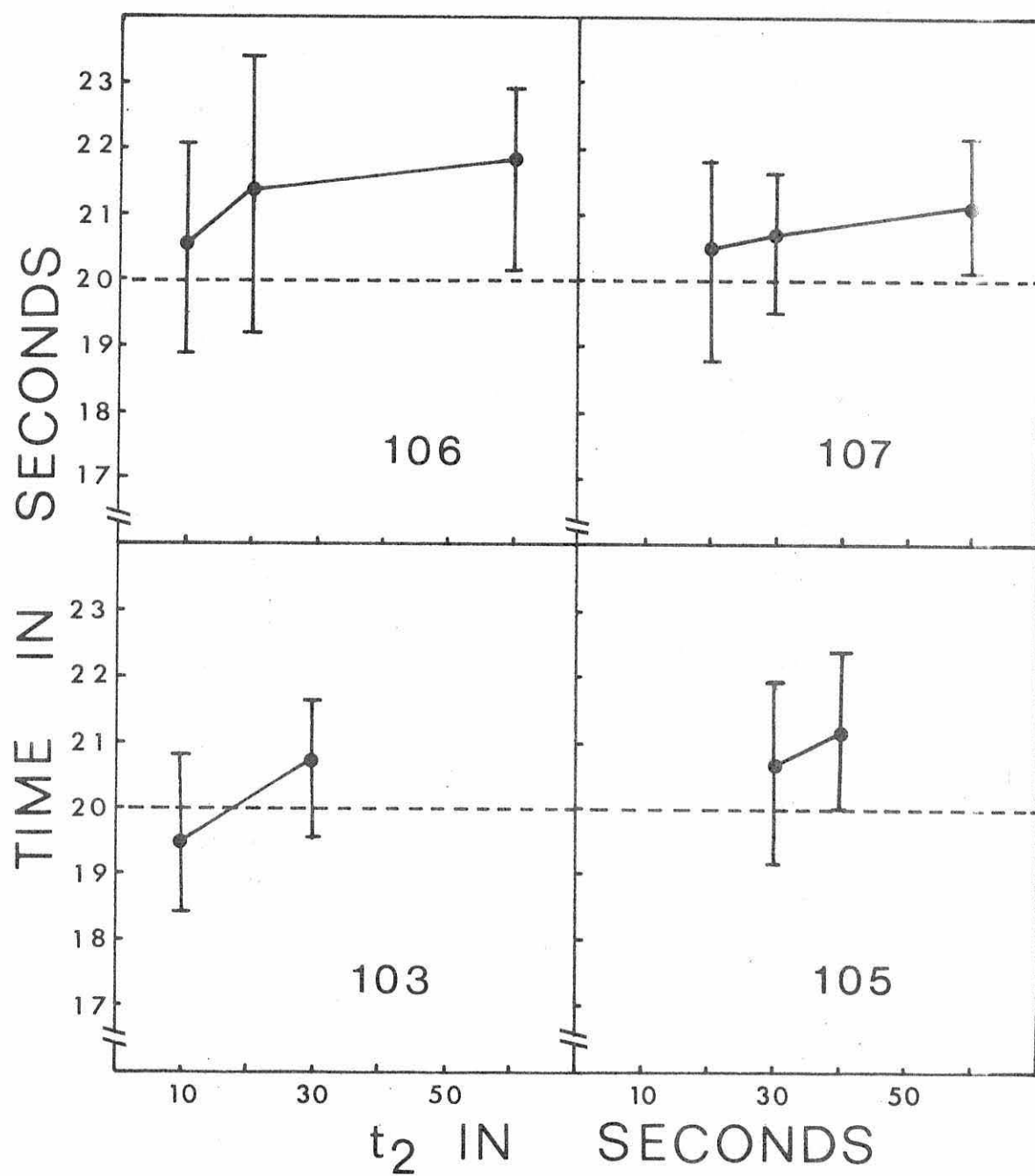
Table 2. Rate of responding and rate of reinforcement for each subject, showing separately, overall rate, rate in the t_1 component and rate in the t_2 component. The time spent in the t_1 component is also shown. Data are from the last two sessions on each schedule.

Subject	Schedule Parameters (t_1=20sec) t_2 (sec)	Responses/min			Reinforcements/min			Time in t_1 (%)
		t_1	t_2	Overall	t_1	t_2	Overall	
	10	2.89	4.82	3.43	1.76	2.90	2.07	73
106	20	2.86	3.53	3.17	2.02	1.60	1.89	66
	60	2.84	2.48	2.68	2.25	0.62	1.45	51
	20	3.03	4.73	3.96	1.80	1.14	1.43	45
107	30	2.91	3.44	3.18	1.98	0.72	1.30	45
	60	2.80	2.44	2.55	2.24	0.34	0.93	32
103	10	3.07	6.20	4.33	1.17	2.91	1.88	60
	30	2.94	3.55	3.33	2.05	0.60	1.09	34
105	30	2.88	2.13	2.47	1.86	0.93	1.36	46
	40	2.85	2.09	2.50	2.15	0.82	1.52	53

Figure 7. Efficiency of performance as
a function of the minimum IRT criterion
on the t_2 component. Overall efficiency
is shown (open circles) as well as
efficiency on the t_1 (filled circles) and
t_2 (filled squares) components. Efficiency
was calculated as the percentage of
responses which were reinforced. Data are
from the last two sessions on each schedule,
for each subject.
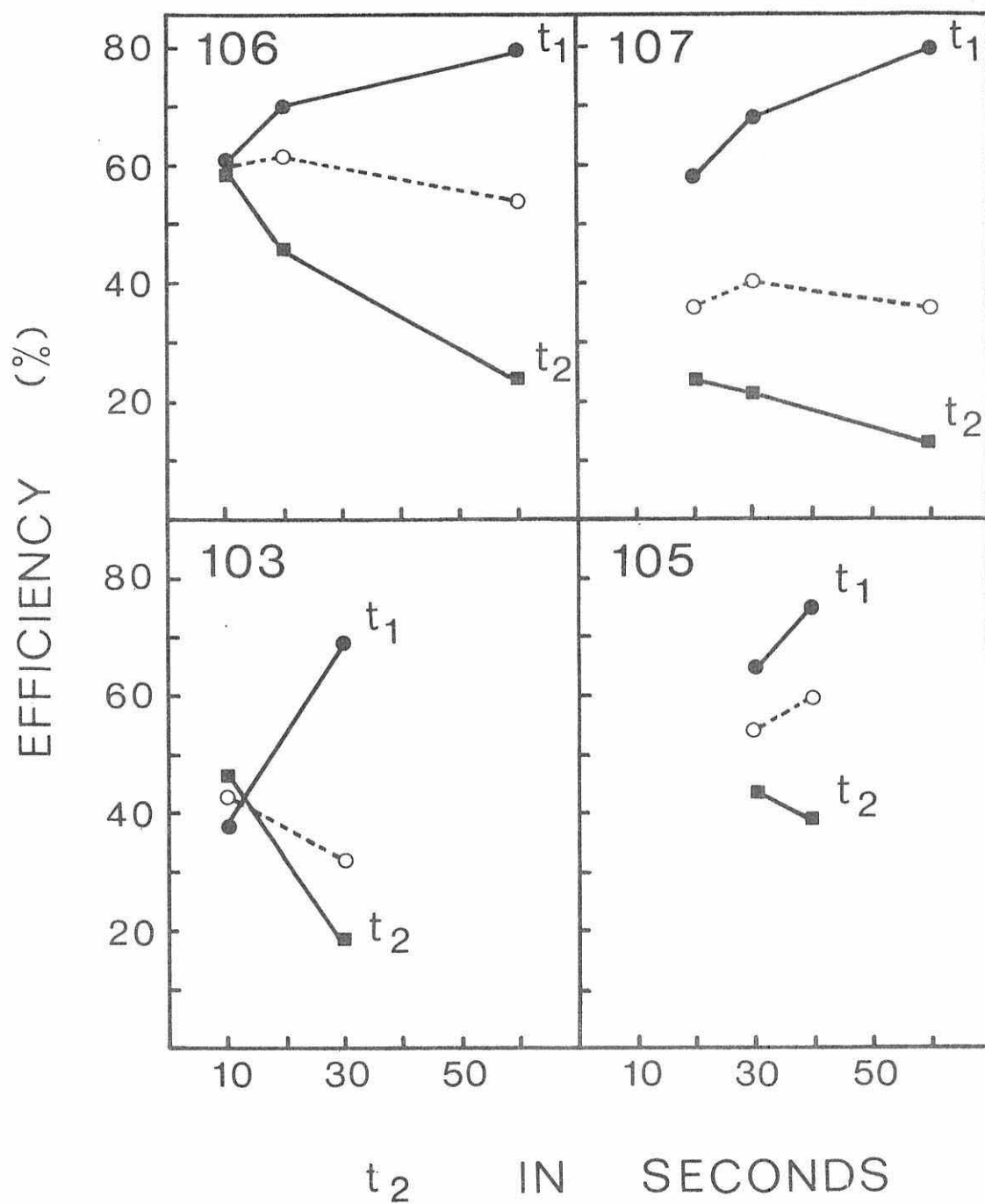
Rate of reinforcement for each animal on the
different schedules is also shown in Table 2.   In
all cases, as the value of the t_2 requirement increased
the rate of reinforcement (i) decreased in the t_2
component,(ii) increased in the t_1 component, (iii)
decreased over both components combined, i.e., the
overall rate declined.   The exception in the
latter case was Animal 105, which showed an increased
overall reinforcement rate when changed from DRL 20-30
to DRL 20-40.

Table 2 shows that as the t_2 requirement became longer,
there was some tendency for less time to be spent in the
t_1 component than in t_2.   This relationship was reversed
for Animal 105.

Efficiency of performance on the t_1 and t_2 components
and overall efficiency are shown (Figure 7) as a function
of t_2, for each animal.   There was a marked contrast in
the effects on efficiency in both components: a decline
in t_2 (filled squares) was matched by a corresponding
increase in efficiency in t_1 (filled circles).   Overall
efficiency (open circles) on the other hand, showed little
systematic change, in all the four animals.

Figure 8 shows, for each animal, the conditional probability* of a burst (i) following non-reinforced responses on t_1 (crosses), and (ii) following non-reinforced responses on t_2 (filled circles), as a function of t_2 duration. A burst never occurred after a reinforced response. The probability of a burst occurring after a non-reinforced response in the t_1 component increased as a function of t_2; there was no systematic effect on burst probability following t_2 responses. In all cases where the duration of t_2 was as long or longer than t_1, the probability of a burst was higher following t_1 than t_2 responses. When t_2 was only 10 sec the functions converged for Animal 106 and crossed over in the case of Animal 103.

Discussion

There was distinct control of responding in each component of the two-component schedules. This was shown in the relative frequency distributions of IRTs

.* calculated by dividing the number of times a burst followed a non-reinforced t_1 response (or a non-reinforced t_2 response) by the total number of non-reinforced t_1 responses (or non-reinforced t_2 responses).

Figure 8. The conditional probability
of a burst as a function of the minimum
IRT criterion on the t_2 component (i)
following non-reinforced responses on the
t_1 component (crosses), and (ii) following
non-reinforced responses on the t_2 component
(filled circles). Data are from the last
five sessions on each schedule for each
subject.
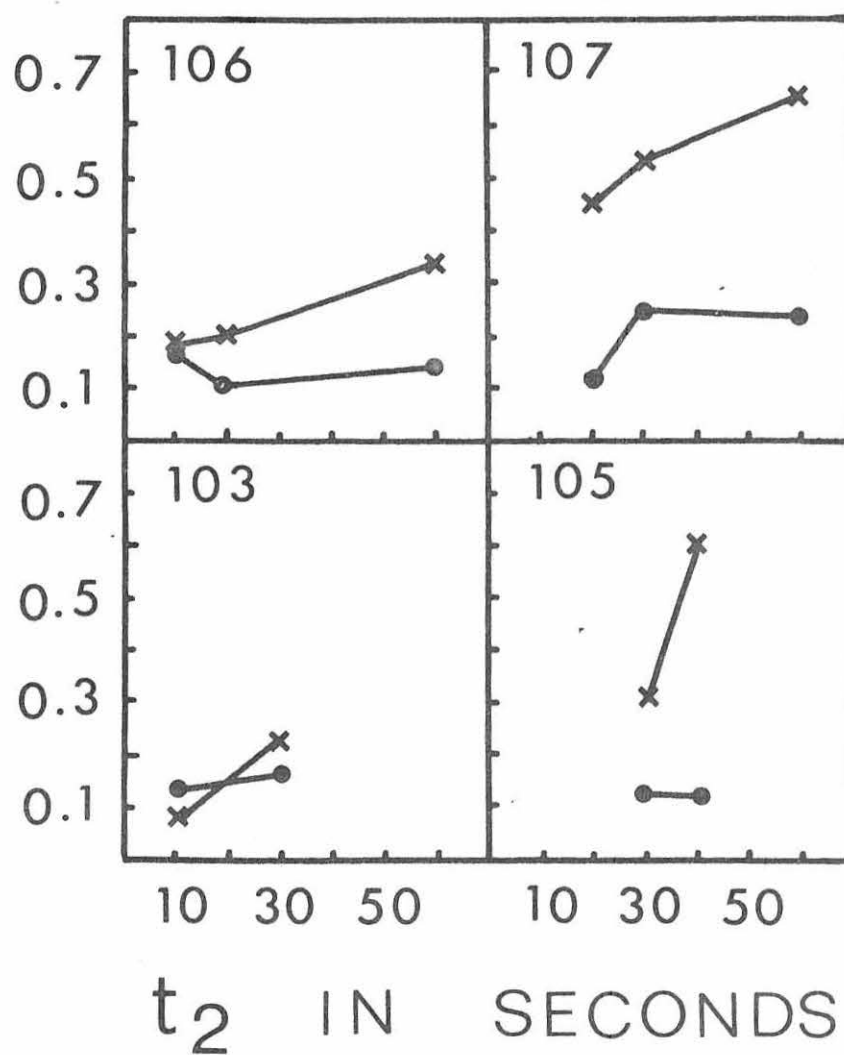
and in the IRT sequences. Following reinforced responses
IRTs were close to the t_1 criterion; when a non-
reinforced response occurred there was frequently either
a burst or the IRT approximated the t_2 requirement. Since
there were no external cues, it would appear that the
controlling stimuli were reinforced and non-reinforced
responses.

There is some evidence which supports this suggestion.
Logan (1967), using a mixed (mix) DRL DRL schedule,
showed that, following reinforcement, animals tended to
emit an IRT which approximated the shortest of the two
DRL requirements. On some schedule values (mix DRL
5-30, 10-30), IRTs following non-reinforced responses
approximated the longer, 30-sec, requirement while on
others (mix DRL 15-30, 20-30) responding was more variable
and a peak at 30 sec was absent.

Unlike the subjects in Logan's study, the subjects
in the present experiment did not adopt the strategy
of emitting an IRT in the region of the shortest IRT
requirement following reinforcement but rather IRTs
occurred which were appropriate to the contingency in
operation. There was no breakdown in the separate
control of either component when the DRL values were
close together, e.g., on DRL 20-30 and DRL 20-10. These

differing observations are due perhaps to the fact that
in the present study specific IRT requirements were
scheduled following reinforced and non-reinforced
responses, while in Logan's experiment either requirement
occurred randomly following reinforcement.

Although much of the evidence in the present
study regarding the stimulus effects of reinforced and
non-reinforced responses has been obtained from those
two-component schedules in which the t_2 requirement
differed from that of t_1, the orderliness of the functions
obtained at all values of the t_2 criterion suggests that
these stimulus effects are also present in the conventional
DRL schedule and that it may be helpful to regard the
conventional schedule as a special case of the two-
component DRL, in which the t_1 and t_2 requirements are
of equal duration.

Given that separate discriminative control was
established in each component, the changes in performance
in the t_2 component as a function of the DRL criterion
on t_2 were similar to those reported previously with
conventional DRL schedules: response rate, reinforcement
rate and efficiency declined and there was a progressive
flattening of the t_2 IRT distributions as the IRT

requirement was increased (Wilson and Keller, 1953; Zimmerman and Schuster, 1962; Smith and Clarke, 1974).

There was a decrease in response rate and an improvement in efficiency in the t_1 component as the duration of the t_2 requirement was increased. These changes in performance in the t_1 component occurred despite the fact that (i) the reinforcement contingency remained constant on the t_1 component at all values of t_2, and (ii) most animals spent less time in the t_1 component as the t_2 requirement became longer. In the light of these relationships it seems likely that the longer delay of reinforcement produced by an increase in t_2 may have functioned as a punishing event; increasing this delay decreased the frequency of the IRT class upon which it was contingent, i.e., IRTs in t_1 shorter than 20 sec. This clearly supports the suggestion that the delay contingency on DRL has punishing or aversive effects (Hearst et al., 1964; Kramer and Rilling 1970; Richelle, 1972; Davis and Iriye, 1973).

The finding that bursts occurred only following non-reinforced responses is consistent with a number of reports (Sidman, 1956; MacDougall et al., 1969; Bradley, 1971) and with the suggestion that bursts are a function of the frustrative or aversive effects of non-reward (Caplan, 1970). Skinner (1950), for example, has

observed, "When we fail to reinforce a response that has previously been reinforced ...we set up an emotional response - perhaps what is often meant by frustration (p.204)". Amsel (1958, 1962) has also argued that omission of an expected reinforcement produces an aversive, motivational condition, "frustration", which leads to heightened activation; the greater the expectancy of reward the greater is the frustration following reward omission (Amsel, 1958).

This explanation is supported by the data from subjects on DRL 20-20 schedules (Figure 8) which show that the probability of a burst was higher following the first non-reinforced response after reinforcement than following other non-reinforced responses -- a result consistent with that reported by Bradley (1971). As the probability of reinforcement was higher following reinforcement than following a non-reinforced response the "expectancy" of reinforcement should also have been stronger following a reinforced response. Frustrative non-reward theory (Amsel, 1958), would on these grounds predict a greater frustration effect and more rapid responding following the first non-reinforced response after a reinforcement.

The probability of a burst following a response was also found to be affected by the consequences of that response; the frequency of bursts following t_1 responses was a direct function of the duration of the IRT requirement in t_2. When the contingency was switched by a non-reinforced response in the t_1 component, the probability of a burst was an increasing function of the extent to which that switch was unfavourable.

The direct relationship between bursts following t_1 responses and the duration of the t_2 requirement is also consistent with Amsel's frustrative non-reward theory. The efficiency data (Figure 7) show that as the duration of t_2 became longer the proportion of reinforced t_1 responses increased. The expectancy of reinforcement following t_1 responses should also have increased concomitantly. When t_1 responses on schedules with higher t_2 values went unreinforced, frustration should thus have been greater and response bursts more frequent than on lower values of t_2.

In view of what has been said regarding a "response bias" in favour of short IRTs (Malott and Cumming, 1966; Logan, 1967; Shimp, 1969), and the tendency for animals to "maximise" reinforcement (Logan, 1960; Logan and

Ferraro, 1970), one remarkable feature of the present experiment was the persistence of the distinct separate control of responding in the two components of the DRL 20-10 schedule; reinforcement was most often followed by IRTs of approximately 20 sec duration, while the 10-sec IRTs occurred after "errors" on the t_1 component or after other non-reinforced responses. Had the subjects produced short IRTs on t_1, thus switching to the shorter t_2 contingency, the frequency of reinforcement might have been increased substantially. This pattern of responding, which might be considered an optimal strategy on DRL 20-10 and also the strategy most likely to be adopted, given that there is a response bias in favour of short IRTs, never developed in the many sessions conducted in this experiment.

EXPERIMENT 2

A feature of the performance on the two-component schedules studied in Experiment 1 was the persistence of control by the t_1 component in the DRL 20-10 schedule. In this experiment the limits of the differential control in the two components were explored when the duration of the t_2 requirement was shorter than t_1.

For one subject, t_1 was kept constant at 20 sec and the duration of t_2 was reduced in graduated steps from 20 sec to 1 sec and then returned in graduated steps to 20 sec. It was expected that at some value of t_2 lower than 10 sec, the animal would adopt an optimisation strategy and cease to emit IRTs of approximately 20 sec after reinforcement. For example, on DRL 20-5, 5-sec IRTs following both reinforced and non-reinforced responses would provide a much higher reinforcement frequency than would the two-component strategy.

Because of the possibility that the gradual reduction in the t_2 requirement of 1 sec might affect the persistence of t_1 control, another subject, following exposure to DRL 20-20, was placed directly on DRL 20-1,

without the intervening steps, and was then returned again to DRL 20-20.

Another possibility was that prior exposure to a long t_2 duration, _i.e._, of 20 sec, might affect subsequent performance on two component schedules with shorter t_2 values; control by the 20-sec t_1 component might be enhanced, for example, on DRL 20-1 given prior exposure to DRL 20-20. To investigate this, two further animals were initially placed on DRL 20-1 and the t_2 value was increased in graduated steps to 20 sec and then returned, without the intervening steps to 1 sec.

Subjects

Four experimentally naive male albino rats (113, 118, 120 and 143), 90-days old at the start of the experiment, served as subjects.

Procedure

Following lever training the subjects were placed on one of the schedules studied in this experiment, in daily sessions. The durations of t_2 used, the sequence in which each animal was exposed to different schedules and the number of sessions on each schedule are

shown in Table 3. Sessions were programmed to last
40 min, rather than 1 hour, in order to avoid
satiation effects at low schedule values. Because
performance remained relatively stable in Experiment 1
once the formal stability criterion was reached, in
Experiment 2 the next schedule was initiated soon after
the formal stability criterion and visual inspection of
the records showed that responding was stable.

Results

The relative frequency distribution of IRTs for the
t_1 and t_2 components, obtained in the last two sessions
of each condition with each subject, are shown in
Figures 9, 10, 11 and 12. Corresponding overall
frequency distributions are presented in the Appendix
(Figures 59, 60, 61, 62). The data from Animal 113
(Figure 9) show that, on almost all values of t_2, the
distribution on the t_2 component was bi-modal with the
first mode occurring in the shortest IRT class interval
and the second mode approximating the IRT requirement in
t_2.

The distributions on t_1 shifted toward shorter IRTs
as t_2 was reduced to 3 sec and particularly when t_2
was only 1 sec; as t_2 was again increased the mode
shifted back toward longer IRTs. Although the mode of
the t_1 distribution shifted, to some extent, as a function

Table 3

Order of exposure to the schedules and the
number of sessions on each schedule, for
individual subjects. The columns listing the
number of sessions also indicate from top to
bottom, the sequence of the schedules for each
subject.

Schedule Parameters t_1-t_2(sec)	Subject			
	113	143	118	120
	Number of Sessions			
DRL 20-20	45	45		
DRL 20-10	23			
DRL 20-5	21			
DRL 20-3	20			
DRL 20-1	21	24	21	20
DRL 20-3	24		24	23
DRL 20-5	22		24	23
DRL 20-10	22		25	24
DRL 20-20	23	25	24	23
DRL 20-1			20	21

Figure 9. The relative frequency

distributions of IRTs for Animal

113 on each schedule. The frequencies

are shown separately for the t_1 and t_2

components. The data are from the

last two sessions on each schedule.
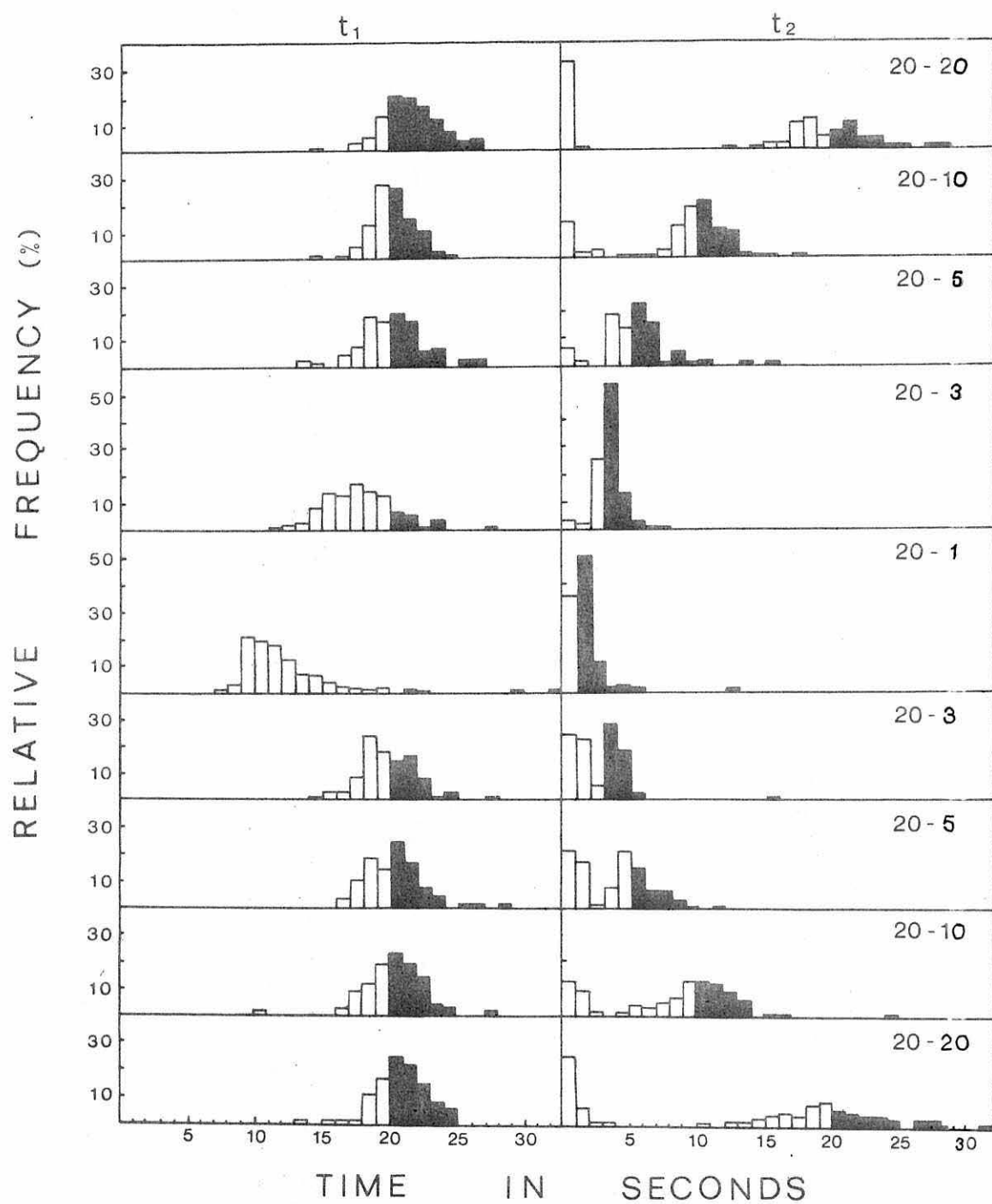
Figure 10. The relative frequency
distributions of IRTs on each schedule
for Animal 143. The frequencies are
shown separately for the two components
of the schedules. The data are from
the last two sessions on each schedule.
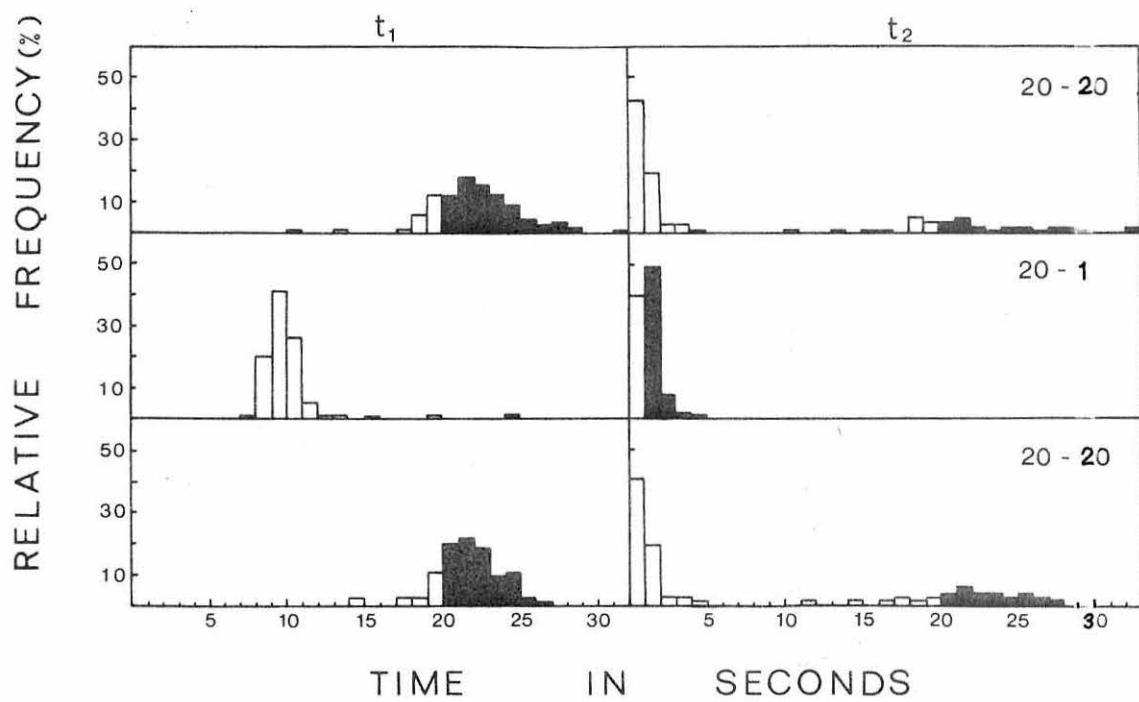
Figure 11. The relative frequency
distributions of IRTs on each
schedule for Animal 118. The
frequencies are shown separately for
the two components of the schedules.
The data are from the last two sessions
on each schedule.

FREQUENCY (%)

RELATIVE

t₁   t₂

20 - 1
20 - 3
20 - 5
20 - 10
20 - 20
20 - 1

TIME   IN   SECONDS
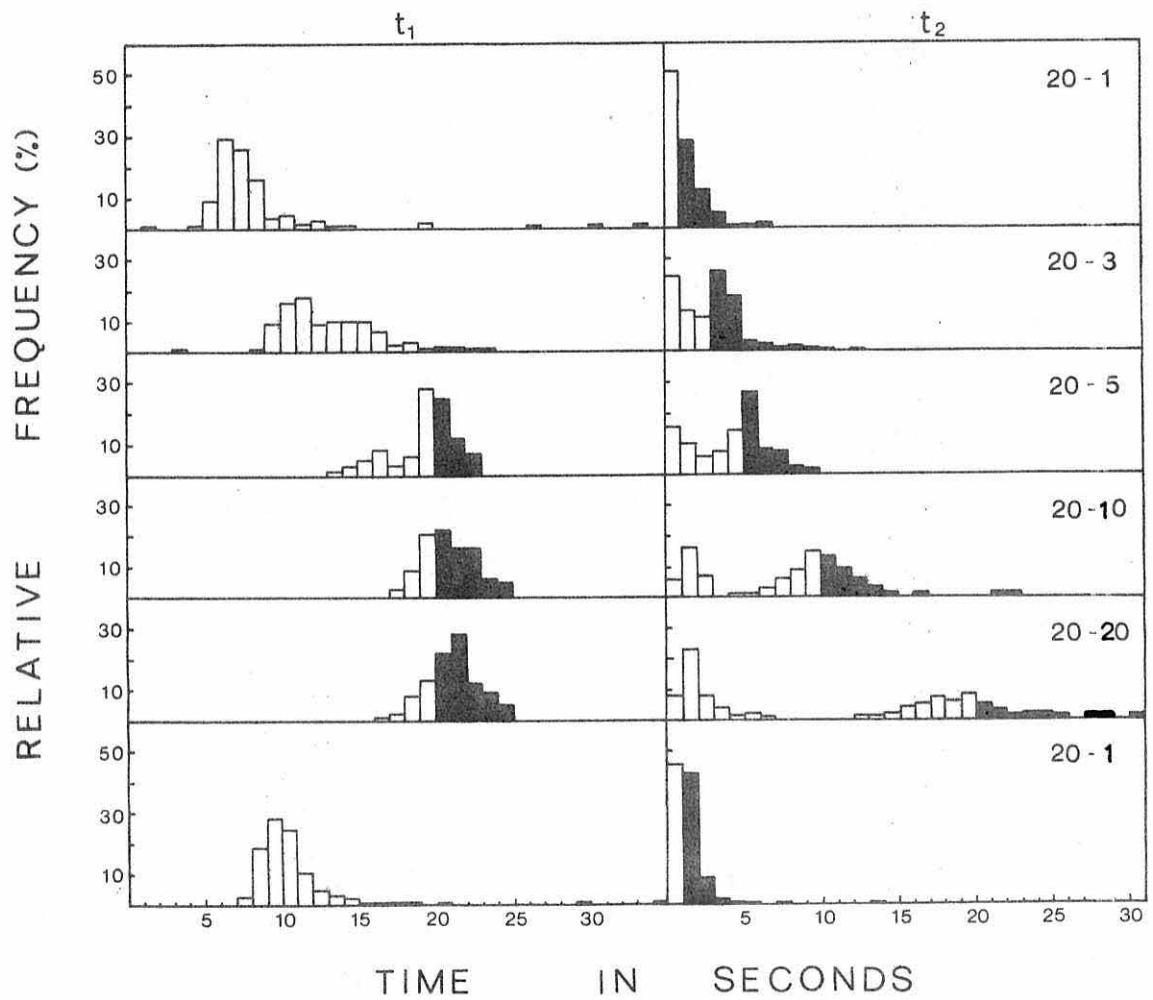
Figure 12. The relative frequency distributions of IRTs on each schedule for Animal 120. The frequencies are shown separately for the two components of the schedules. The data are from the last two sessions on each schedule.
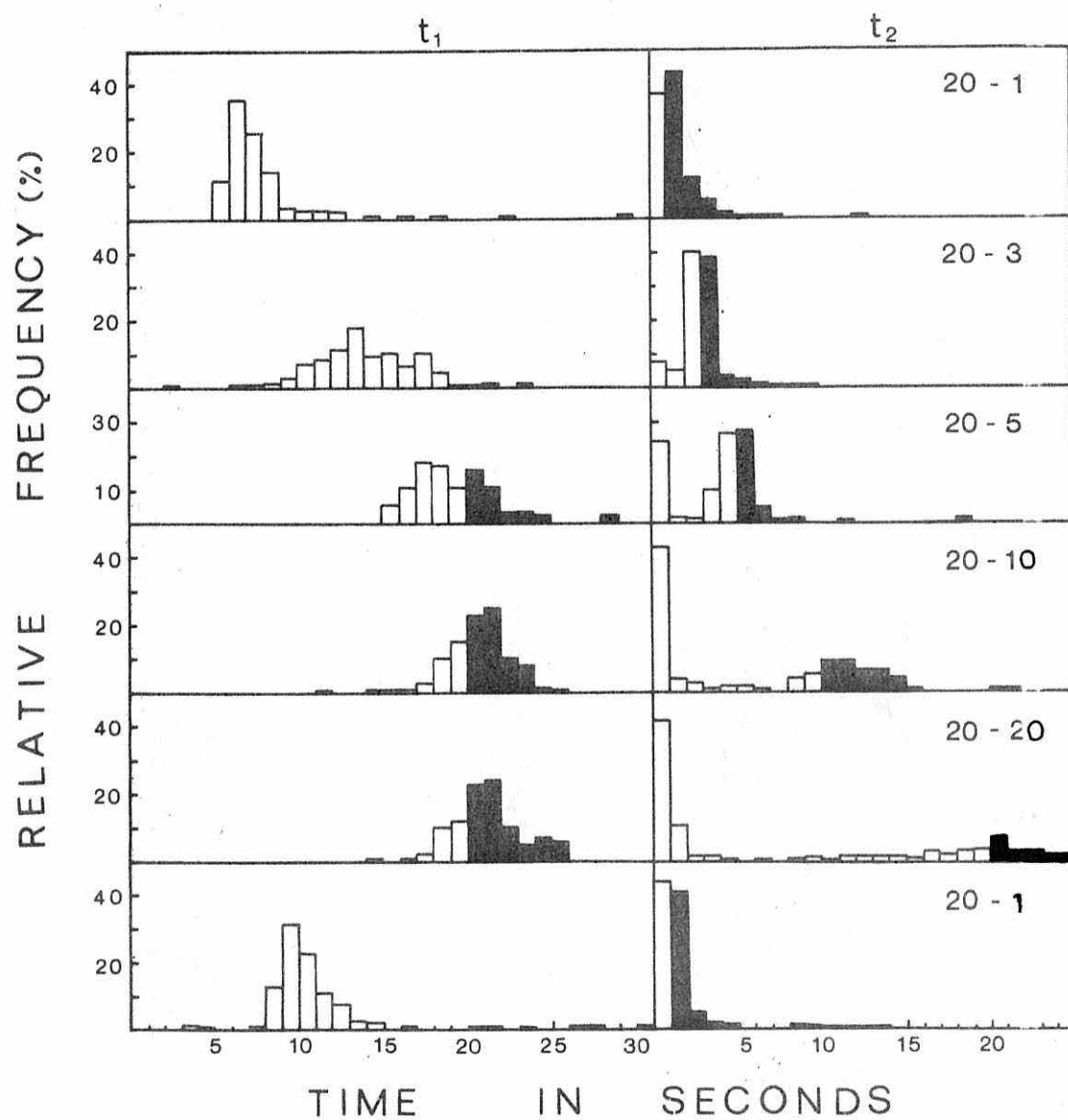
of t_2 duration, it was usually in the region of the 20-sec IRT requirement; the exception to this was the distribution on DRL 20-1.

This relationship between the duration of IRTs on t_1 and duration of t_2 is also shown in Figure 13, which presents for each subject the median and interquartile range of IRTs on t_1 as a function of t_2. Though the median IRT, for Animal 113, decreased as t_2 became shorter, on most conditions the median was close to the t_1 requirement; again the greatest deviation from the 20-sec criterion took place when the duration of t_2 was 1 sec. The frequency distributions (Figure 10) and the median IRTs on t_1 (Figure 13) for Animal 143, on DRL 20-20, DRL 20-1 and DRL 20-20 respectively, are similar to those of Animal 113 on the same schedule values.

The distributions for Animals 118 and 120 are presented in Figures 11 and 12 respectively. In both cases the relative frequency of the IRTs in the t_2 component shows the same matching of the t_2 requirement seen in Animals 113 and 143. Though the mode of the IRT distributions on t_1 shifted toward longer IRTs as t_2 was increased, when t_2 was either 1 sec or 3 sec almost

Figure 13. The median and interquartile range of IRTs on the t_1 component, as a function of the minimum IRT criterion on the t_2 component. Data are from the last two sessions on each schedule for each subject.
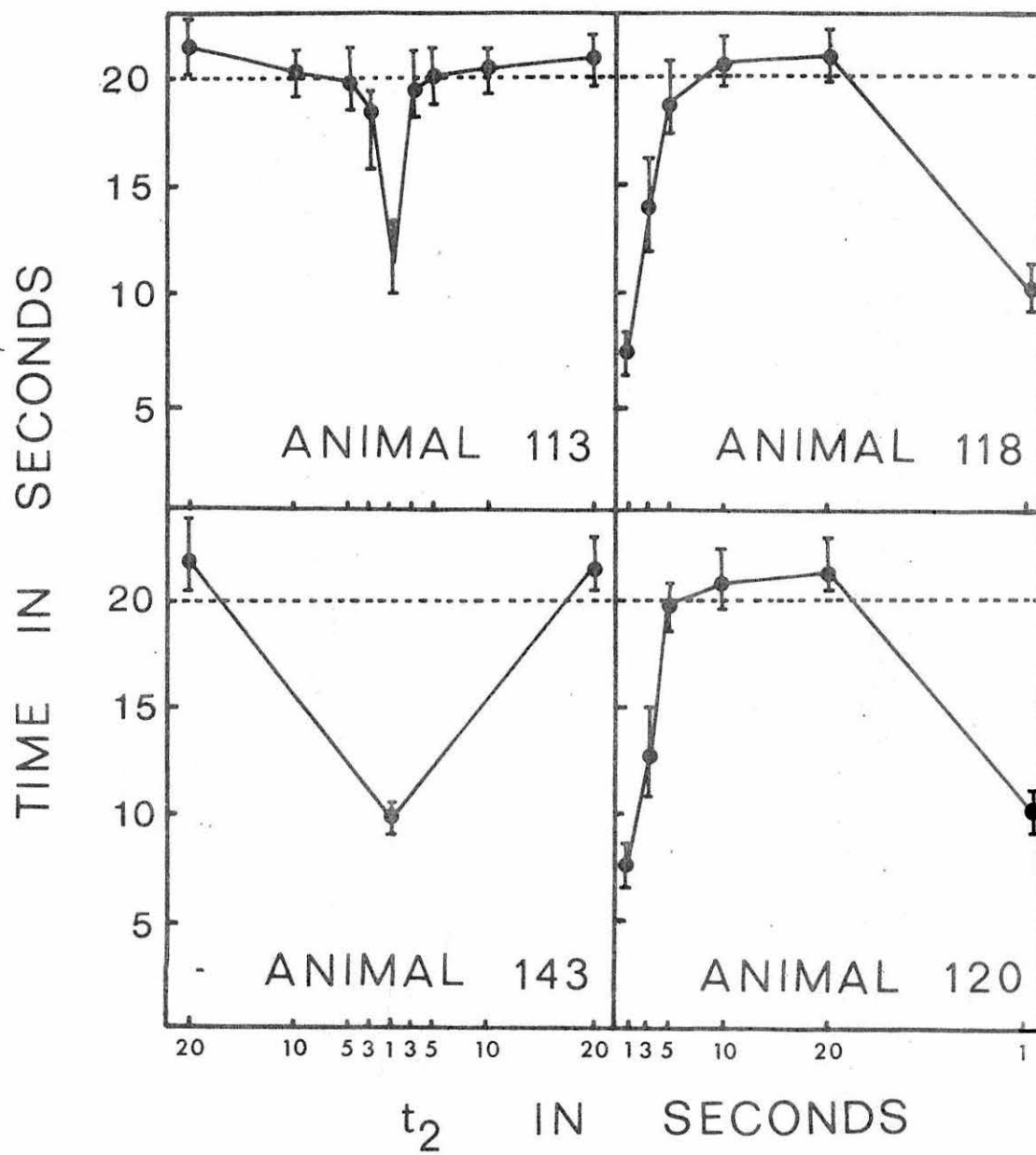
no IRTs occurred which met the 20-sec criterion. For both Animals 118 and 120, a peak did not appear in the region of the minimum reinforced IRT until the t_2 requirement was increased to 5 sec. The mode then remained around 20 sec, though IRTs became longer as the duration of t_2 was further increased.

These relationships can also be seen in the changes in median IRT on t_1 (Figure 13); the median IRT increased linearly as t_2 was increased to 5 sec but the function sloped off at higher values of t_2.

The median IRT functions for Animals 118 and 120 also reveal differences with the other two subjects. Taking for example, performance on DRL 20-1, the two subjects with prior exposure to the long t_2 duration of 20 sec, Animals 113 and 143, produced median IRTs which were longer than those of the two subjects placed "naïve" on this schedule. When Animals 118 and 120 had been exposed to longer durations of t_2 and were then returned to DRL 20-1 the median IRTs on t_1 did not return to their former levels but were of longer duration, similar to those of Animals 113 and 143.

For all subjects, the data relating to response rate, reinforcement rate and amount of session time spent in the t_1 component are presented in Table 4. The rate of responding in the t_1 and t_2 components, as well as overall response rate, were inversely related to the duration of the t_2 requirement. The rate of reinforcement in the t_2 component and overall was an inverse function of t_2 duration, while in the t_1 component it was directly related to the t_2 requirement. The time spent in t_1 was generally shorter as the t_2 criterion became longer, but this relationship showed some variability.

Figure 14 shows the efficiency of performance on each schedule value, for each animal. Overall efficiency showed little systematic change as a function of the t_2 criterion. There were however, substantial effects on efficiency in each of the two components: as the duration of t_2 became longer, efficiency declined on t_2 but increased on the t_1 component.

Data were also recorded when the animals were responding on CRF, at the beginning of the experiment. The mean duration of IRTs was approximately 3 sec for each subject.

Table 4. Rate of responding and rate of reinforcement for each subject, showing separately, overall rate, rate in the t_1 component and rate in the t_2 component. The time spent in the t_1 component is also shown. Data are from the last two sessions on each schedule.

Subject	Schedule Parameters (t_1=20sec) t_2 (sec)	Responses/min			Reinforcements/min			Time in t_1 (%)
		t_1	t_2	Overall	t_1	t_2	Overall	
	20	2.77	4.39	1.89	2.20	1.41	1.15	66
	10	2.97	6.97	4.20	1.61	3.07	2.06	69
	5	3.00	10.94	4.42	1.53	6.79	2.47	82
	3	3.38	17.84	6.05	0.57	12.38	2.75	82
113	1	4.91	40.23	10.32	0.16	26.29	4.16	85
	3	3.00	23.09	5.77	1.30	10.66	2.59	86
	5	2.97	15.91	5.62	1.63	5.26	2.37	80
	10	2.94	7.14	4.04	1.77	3.34	2.18	76
	20	2.88	4.29	3.50	2.04	1.06	1.61	56
	20	2.76	7.60	3.98	2.16	1.77	2.06	75
143	1	6.24	48.55	13.69	0.12	28.60	5.14	82
	20	2.78	7.03	4.06	2.30	1.27	2.02	73
	1	7.72	39.50	15.07	0.07	25.40	5.93	77
	3	4.38	20.57	9.31	0.18	9.63	3.05	70
118	5	3.11	15.04	6.31	1.17	5.29	2.27	73
	10	2.93	10.13	4.40	2.03	3.45	2.32	79
	20	2.84	7.55	4.57	2.09	1.29	1.80	63
	1	5.56	35.80	12.53	0.20	17.90	4.28	77
	1	7.39	44.89	16.87	0.11	21.50	5.52	75
	3	4.52	20.64	9.18	0.21	10.61	3.22	71
120	5	3.09	14.13	5.39	1.37	6.53	2.45	79
	10	2.87	7.62	4.13	1.92	2.60	2.10	73
	20	2.84	5.39	3.84	2.16	1.06	1.73	61
	1	5.63	48.47	13.14	0.09	26.10	4.65	82

Figure 14. Efficiency of performance
as a function of the minimum IRT
criterion on the t_2 component. Overall
efficiency is shown (open circles) as
well as efficiency on the t_1 (filled
circles) and t_2 (filled squares)
components. Unconnected symbols indicate
redetermination points. Data are from
the last two sessions on each schedule,
for each subject.
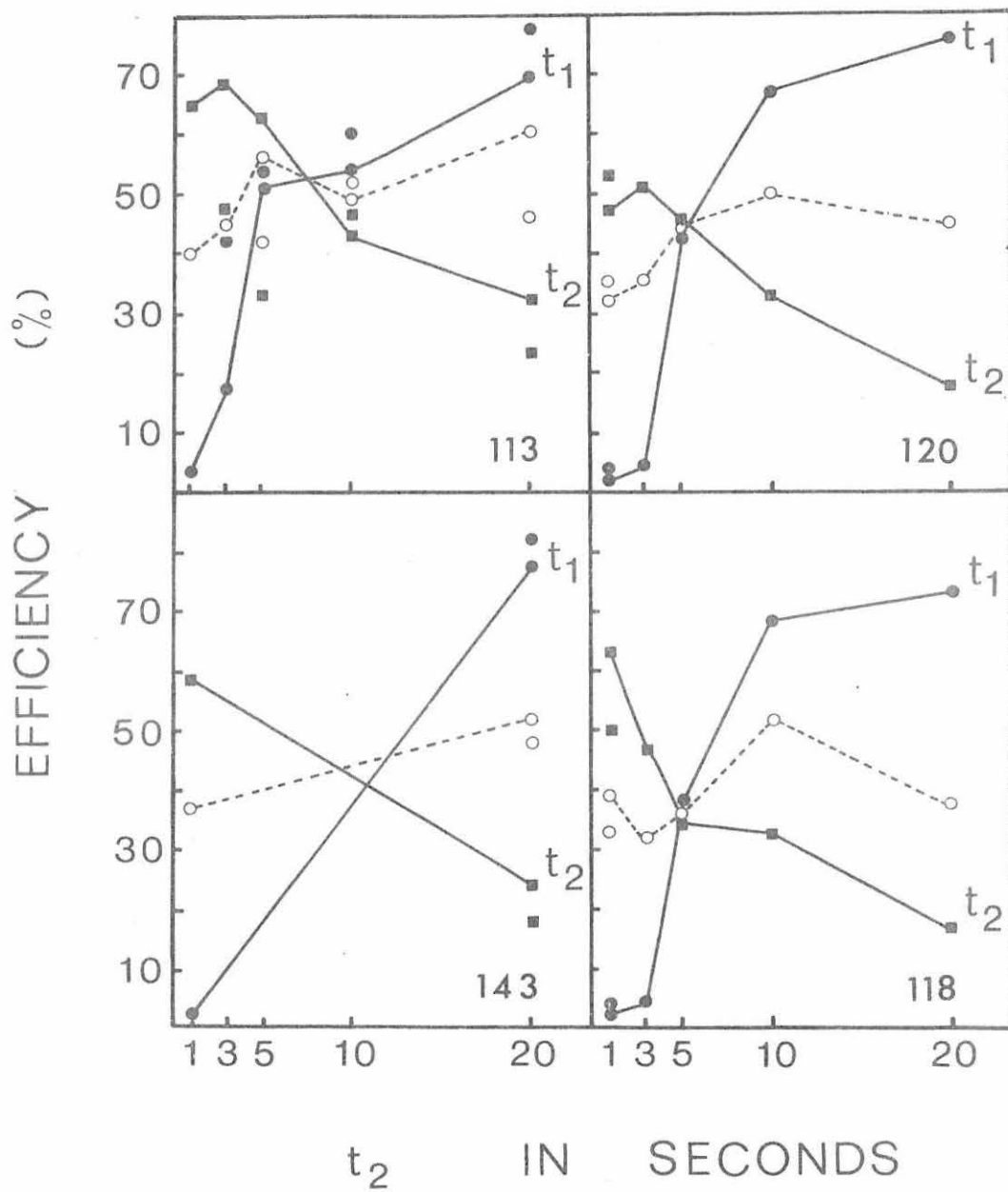
Discussion

Despite the fact that all the t_2 values used were
shorter than t_1 (except when t_2 was equal to t_1), the
relationships observed in Experiment 1 between the t_2
value and in turn response rate, reinforcement rate,
and efficiency, were also found in this experiment.
Differential responding was again observed on both
components of the schedules.

On the basis of the commonly held assumption that
organisms maximise reinforcement, it might be expected
that those subjects on shorter t_2 values, rather than
attempting to meet the 20-sec criterion on t_1, would
respond quickly after reinforcement thus switching to
the shorter requirement. The behaviour observed in
the present experiment confounded this expectation.
Animal 113 for example, continued to emit long IRTs in
t_1, close to the t_1 criterion,even when t_2 was as low
as 3 sec; when t_2 was 1 sec most IRTs in t_1 still
exceeded 10 sec.

The performance of Animal 143 indicates that the
IRTs longer than 10 sec emitted by Animal 113 on DRL
20-1 were not due to the gradual reduction in the t_2
requirement. The value of t_2 was changed abruptly from
20 sec to 1 sec for Animal 143, producing a similar
performance in the t_1 component to that of Animal 113.

The performance of all four animals on DRL 20-1
suggests that the duration of IRTs in the t_1 component
was affected by prior exposure to the t_1 requirement
of 20 sec, established when longer t_2 requirements were
in effect. IRTs in t_1, for those subjects which were
naive when placed on DRL 20-1, were shorter than those
for subjects which had had prior exposure to longer t_2
values. This effect of the sequence in which animals
were exposed to the schedule values is similar to that
reported by Schoenfeld et al. (1970). They observed
that when the probability was low that a 5-sec criterion
was in effect following reinforcement, IRTs were short
(1-2 sec) after reinforced responses. However, following
exposure to higher probability values, which produced
5-sec IRTs after reinforcement, subsequent performance
on the lower probability values contained a greater
proportion of 5-sec IRTs than had occurred originally.

Though prior exposure to the 20-sec requirement of
the t_1 component at higher t_2 values may have affected
subsequent performance in the DRL 20-1 schedule, IRTs
on t_1 were, nevertheless, not very short even when animals
were placed naive on this schedule. Both Animals 118 and
120 for example, emitted IRTs following reinforced
responses which on average exceeded 6 sec during their

first exposure to DRL 20-1, which may be compared with a mean IRT of 3 sec when these subjects were responding on CRF. The duration of these IRTs increased when the t_2 requirement became 3 sec. Both of the animals on DRL 20-3 made little or no contact with the 20-sec t_1 requirement yet IRTs on t_1 mostly exceeded 12 sec and almost all of these were unreinforced.

There appears to be a similarity between the present findings and those of Mechner and Guevrekian (1962) who used a two-lever (response-initiated) DRL schedule, in which a response on the first lever, though initiating the DRL interval, went unreinforced; a response on the second lever terminated the interval. They found that, while IRTs which occurred between the first-lever response and the second-lever response approximated the 5-sec DRL requirement, the duration of post-reinforcement pauses was frequently much longer than 5 sec. Again, in this situation animals did not maximise reinforcement by responding soon after a reinforced response thus initiating the DRL interval (see also Chapter 6, for performance on single-lever response-initiated DRL schedules).

GENERAL DISCUSSION

In both the experiments described in this chapter, a consistent positive relationship was observed between the duration of IRTs in the t_1 component and the duration of the IRT requirement in t_2. In schedules which contain two components, e.g., multiple schedules, different explanations have been proposed to account for the interaction between components.

One such explanation is that of induction (cf. Zimmerman and Schuster, 1962). Applied to the present findings this would suggest that the longer IRTs which occurred in the t_2 component may in some way have generalised to the t_1 component, producing longer IRTs there. Induction effects cannot, however, account for the performance of Animals 118 and 120 when first placed on DRL 20-1 and then on DRL 20-3. Though there was little evidence of any control by the 20-sec t_1 criterion on these schedules, IRTs were nevertheless much longer on t_1 than on t_2. When, for example, the t_2 requirement was 3 sec, it is unlikely that the 12-sec IRTs which occurred on t_1 could have been the result of induction from the 3-sec IRTs of the t_2 component.

Much of the existing experimental evidence
indicates that behavioural contrast, rather than
induction, might result from changes in the t_2 criterion.
In two-component multiple schedules, when the rate of
responding and the rate of reinforcement is reduced
on one of the components, response rate increases on the
second component (Reynolds, 1961; Reynolds and Catania,
1961; Terrace, 1966; 1968). In the present experiments
the decrease in response rate and reinforcement rate on
the t_2 component, when the IRT criterion on t_2 was
lengthened, might thus be expected to produce an increase
in response rate in t_1. As the results from both
experiments clearly show, however, response rate on t_1,
decreased as a function of the duration of the t_2
requirement.

Behavioural contrast has usually been reported in
multiple schedules, which contain discriminative stimuli
present throughout each component. It is possible that the
presence of a stimulus on each component is a necessary
condition for contrast to occur (Staddon, 1974 a) and, of
course, the condition is not met in the two-component
DRL schedules used in Experiments 1 and 2. Though a
contrast in response rates was not observed, it should
be noted that there was a marked and consistent contrast
in reinforcement rate and in efficiency on the t_1 and
t_2 components when t_2 duration was manipulated.

It has been argued (Caplan, 1970; Davis and Iriye, 1973) that the delay contingency on the DRL schedule is aversive, punishing responses which fail to meet the DRL criterion (cf. Chapter 3). The results reported here are consistent with this hypothesis. For all the animals studied, increasing the delay in the availability of reinforcement following responses which failed to meet the t_1 requirement decreased the frequency of these responses; the proportion of non-reinforced responses on the t_1 component consistently decreased as a function of the IRT requirement on t_2.

Response rate also declined on the t_2 component when the IRT requirement was increased. This relationship is similar to the general relationship on DRL schedules between overall response rate and the duration of the IRT requirement (e.g., Wilson and Keller, 1953; Staddon, 1965). The fall in overall response rate on conventional DRL schedules may, however, be due to the lowered rate of reinforcement which results from increasing the DRL criterion, rather than to an enhanced punishing effect of the longer delay requirement (Staddon, 1972). The present results show, on the other hand, that the reinforcement rate explanation cannot account for the lower rate of

responding on the t_1 component, since the reinforcement contingency was held constant on t_1; when reinforcement rate did change on t_1 it increased as a function of the t_2 requirement.

The inverse relationship between reinforcement rate and response rate on t_1 is consistent with the results obtained by Holz et al. (1963). They reported that when response rate on DRL was reduced by response-contingent electric shock the resultant improvement in reinforcement frequency did not, in turn, result in an increase in rate of responding. These findings indicate the relative unimportance of reinforcement rate as a primary determinant of response rate on DRL (cf. Richardson, 1973). According to this evidence, and in view of the demonstrated effects of the delay contingency on response rate in the t_1 component, it appears that a major factor which regulates responding on DRL schedules is the response-produced delay in the availability of reinforcement.

The differential control of responding, appropriate to the schedule values, observed in both components on many values of the two-component schedules, indicates that both reinforced and non-reinforced responses acquired stimulus control of responding and that the suppressive

effects of reinforcement delay operate through these
stimuli. This is consistent with the notion that
the reinforcer on DRL functions as an inhibitory stimulus
(Staddon, 1970 b) and also suggests that non-reinforced
responses may have similar inhibitory effects.
Studies which have shown that both disinhibition effects
of novel stimuli (Contrucci et al., 1971; Brimer, 1972;
Davis and Iriye, 1973) and schedule-induced aggression
(Knutson and Kleinknecht, 1970), occur not just following
reinforcement but throughout the experimental session,
also support the contention that both reinforced and
non-reinforced responses acquire inhibitory properties
on DRL schedules.

The data from subjects on the DRL 20-20 schedules
indicate, on the other hand, that reinforced responses
may be more effective as inhibitory stimuli than those
responses which go unreinforced. Though the IRT
requirement was the same following both events, the
IRT distributions on t_2 contained a higher frequency
of IRTs which failed to meet the DRL criterion and this
appeared to be so even when bursts in t_2 were not taken
into account. These results are consistent with a
number of reports of better DRL performance following
reinforcement (e.g., Farmer and Schoenfeld, 1964 b,
Weiss, 1970). This phenomenon will be considered further
in Chapter 8.

It has been argued, above, that reinforced and
non-reinforced responses function as discriminative
stimuli on two-component DRL schedules. There is,
however, another possible source of stimulus control
which has not been dealt with, namely the discriminative
effect of prior IRT duration. Angle (1970) has shown,
for example, that when two IRT requirements, 5 sec
and 15 sec, are presented in fixed alternation in a
mixed DRL DRL schedule, given that the prior IRT is
reinforced, IRTs tend to alternate, matching the
programmed contingencies. Angle has taken this to
indicate that animals on this schedule discriminate the
duration of the prior IRT, say 5 sec, which sets the
occasion for a subsequent IRT of 15 sec. It is possible
that similar effects were operative in the schedules
used in Experiments 1 and 2. The IRTs which occurred
on each component of the two-component schedules may have
been partly a function of the duration of preceding IRTs.
Taking as an example DRL 20-40, when a reinforced
response occurred on the t_2 component it was usually
followed by an IRT of approximately 20 sec, which might
suggest that the reinforcer was the event controlling
the 20-sec IRT. However, in this case, reinforcement
must have been preceded by an IRT of at least 40 sec.
The switch to an IRT approximating the 20-sec t_1 criterion

might thus have been controlled by a prior IRT of
40 sec or more.

The experiments to be described in the next
chapter provide evidence concerned with this and other
questions related to performance on two-component
DRL schedules.

CHAPTER 6

EXPERIMENTAL MANIPULATIONS ON
TWO-COMPONENT DRL SCHEDULES

The results described in Chapter 5 provide
evidence that both reinforced and non-reinforced
responses function as stimuli, maintaining temporal
control of responding on DRL schedules. The present
chapter attempts to analyse further the stimulus
control of responding on these schedules, and in
particular investigates the role of the reinforcer as
a stimulus.

EXPERIMENT 3

In this experiment a differential stimulus was added
to both components of the two-component DRL schedule.
The schedule thus resembled a conventional multiple
schedule of reinforcement (cf. Zimmerman and Schuster,
1962).

One possible effect of this manipulation was that
the precision of performance on both components might
be enhanced, since a stimulus was constantly present
throughout each component indicating which of the two
IRT requirements was in operation. An improvement in
schedule control might thus be reflected in longer IRTs
or better peaking of the IRT distributions around the
required IRT value in each component.

Subjects

Two experimentally naive male albino rats (101 and
104) 90 days old at the start of the experiment, served
as subjects.

Procedure

Following lever training, Animal 101 was placed on
DRL 20-10 and Animal 104 on DRL 20-40 in daily 1-hour
sessions. These schedule parameters were held constant

throughout the experiment. Stimulus manipulations were carried out in different phases, each manipulation occurring after response stability had been reached in the previous phase.

The subjects remained on both two-component schedules until responding was stable (first phase). In the case of Animal 104, a 75 db tone was then presented while the t_1 component was in operation; for Animal 101, the tone was presented while the t_2 component was in effect (second phase). The component on which the tone stimulus was presented was then reversed for both subjects (third phase). Finally the tone was removed and the conditions present in the first phase were restored (fourth phase).

Both subjects were given a minimum of 40 sessions on the first experimental phase to establish stable schedule performance. The conditions were changed when the formal stability criterion was met and visual inspection of the records showed that responding was stable. Thereafter subjects were given a minimum of 20 sessions on each phase, after which the conditions were again changed, provided that the formal criterion

and visual inspection of the records showed that the
behaviour was stable. The sequence of conditions for
each subject and the number of sessions in each condition
are shown in Table 5.

Results

The relative frequency distributions of IRTs for
the t_1 and t_2 components, obtained in the last two
sessions of each condition, are shown in Figures 15
and 16, for Animals 101 and 104 respectively. Corresponding
overall frequency distributions of IRTs, for both components
combined, are presented in the Appendix   (Figures 63, 64).

Both Figures 14 and 15 show that control was established
in each of the two components of the schedules. The IRT
distributions for the two subjects peaked in the region of
20 sec on t_1; distributions on t_2 were bi-modal, with
the first mode occurring in the shortest IRT interval and
the second mode matching the value of t_2, i.e., the mode
was at approximately 10 sec for Animal 101 and in the
region of 40 sec for Animal 104.

The IRT distributions for each subject were very
similar over all conditions. There appeared to be no
systematic change in the distribution of IRTs on either
the t_1 or the t_2 component when the tone stimulus was
added either to t_1 or to t_2.

TABLE 5

Order of exposure to the experimental conditions (listed top to bottom) and the number of sessions on each condition, for individual subjects.

SUBJECT	SCHEDULE (SEC)		SESSIONS
	t_1	t_2	
	20 —	10	42
	20 —	10^{+tone}	21
101	20^{+tone}	10	20
	20 —	10	22
	20 —	40	45
	20^{+tone}	40	22
104	20 —	40^{+tone}	20
	20 —	40	20

Figure 15. Relative frequency
distributions of IRTs for Animal 101
on the t_1 and t_2 components in each
of the four experimental conditions:
(i) DRL 20-10, (ii) DRL 20-10 with
a tone stimulus added to the t_2
component, (iii) DRL 20-10 with the
tone on the t_1 component, (iv) DRL
20-10 without the tone stimulus. Data
are from the last two sessions on each
condition.
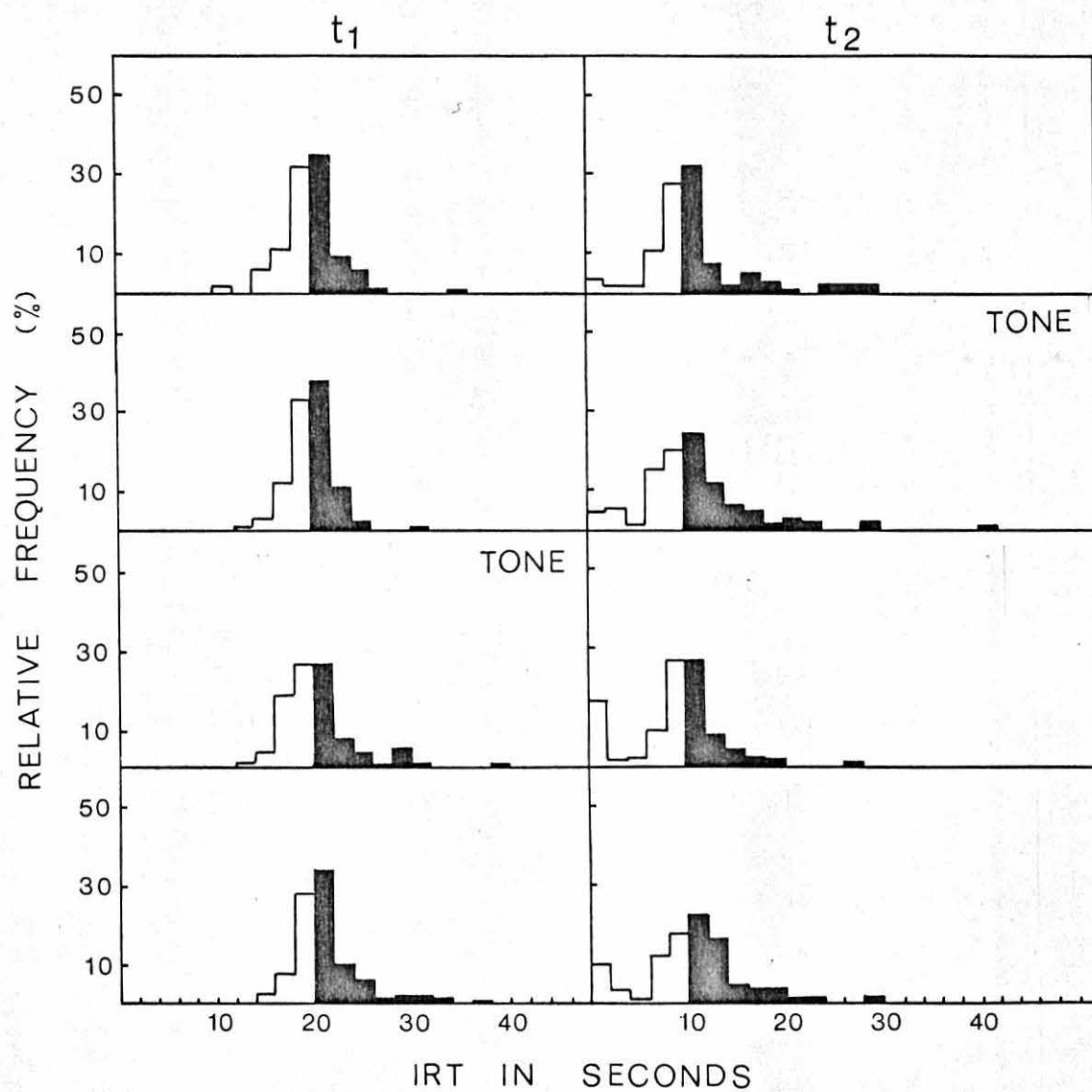
Figure 16. Relative frequency
distributions of IRTs for Animal 104
on the t_1 and t_2 components in each
of the four experimental conditions:
(i) DRL 20-40, (ii) DRL 20-40 with
the tone stimulus added to the t_1
component, (iii) DRL 20-40 with the
tone on the t_2 component, (iv)
DRL 20-40 without the tone stimulus.
IRTs on the t_2 component which were
longer than 54 sec are contained in
the final IRT category. Data are from
the last two sessions on each condition.
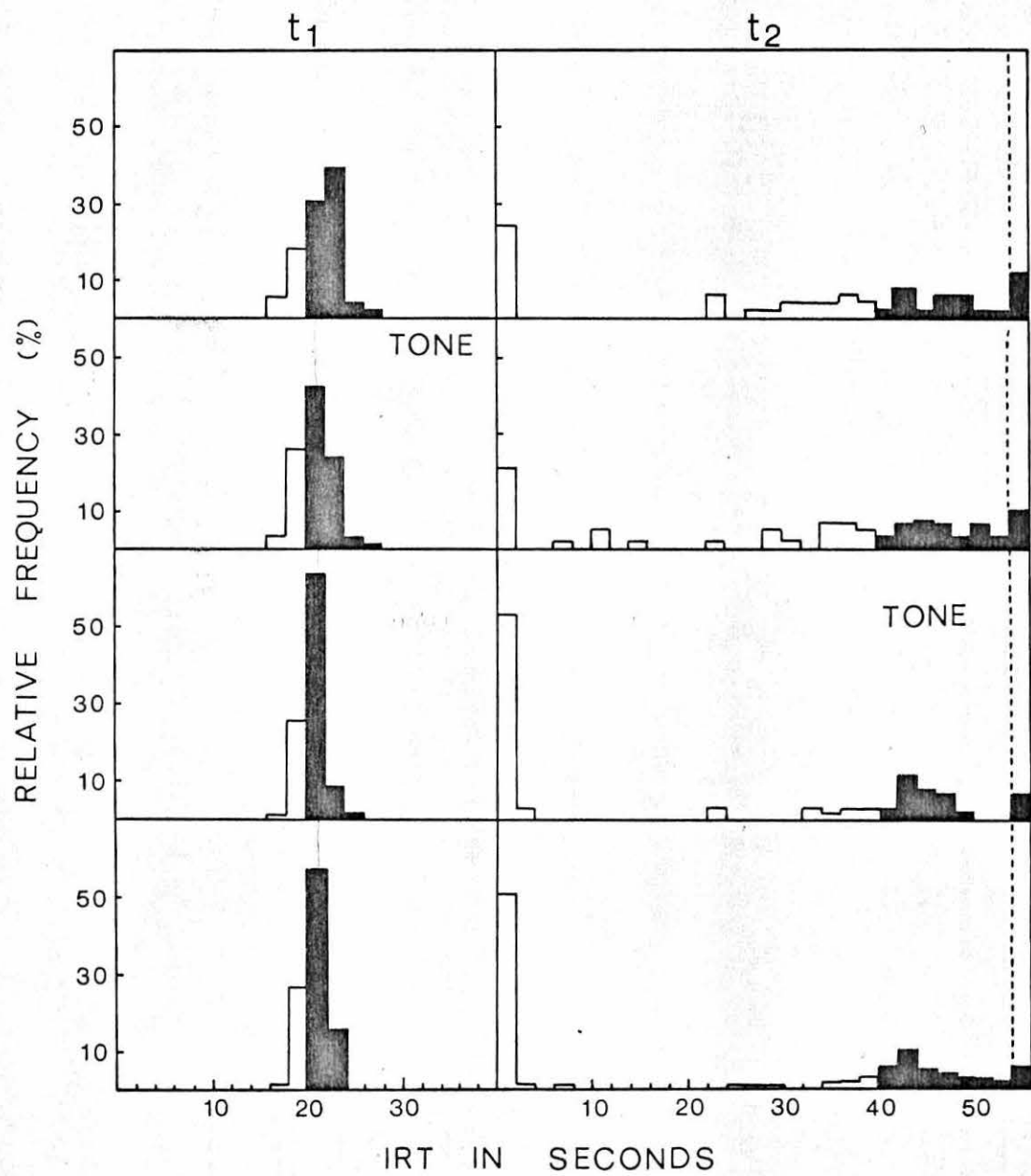
The median and interquartile range of IRTs on t_1
for each subject on the four conditions are shown
in Figure 17. As might be expected from the frequency
distributions for both animals, no systematic change
in performance was evident when the tone was added to
either component.

Discussion

One reason postulated by Hearst et al. (1964) to
account for the flat stimulus generalisation gradients
they obtained from subjects on DRL schedules was that
DRL performance may be under the control of internal
proprioceptive stimuli, in which case additional stimuli
would be more or less irrelevant to the subject. The
results from the present experiment also indicate that
the provision of different stimulus conditions on both
components of a two-component DRL schedule does not
alter the pattern of responding. According to the
present evidence, however, the sources of stimulus control
which make additional stimuli redundant, are reinforcements
and the operant responses of the subject.

A feature of performance in Experiments 1 and 2 was the
failure of the subjects, on schedules in which the duration
of t_2 was shorter than that of t_1, to initiate the shorter
t_2 requirement by responding soon after reinforcement. On

Figure 17. The median and
interquartile range of IRTs on the
t_1 component for each subject in each
of the four experimental conditions:
(i) the baseline DRL schedule, (ii)
tone stimulus (T) added to one of the
schedule components, (iii) tone
presented on the other component,
(iv) tone stimulus removed. Data are
from the last two sessions on each
condition.
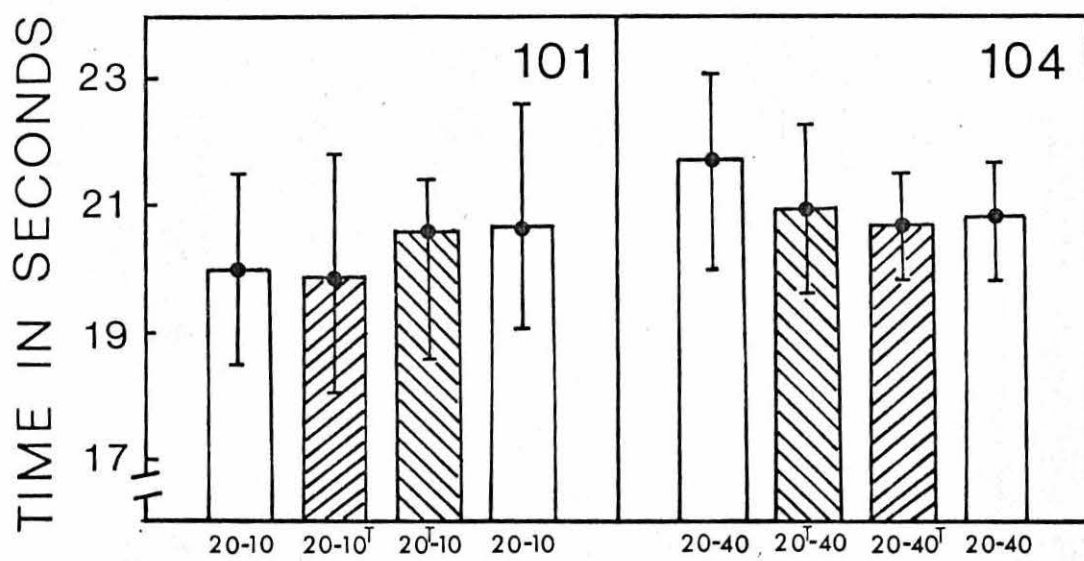
DRL 20-10, for example, subjects waited approximately 20 sec following reinforcement before making a response, whereas a response soon after reinforcement would have allowed reinforcement to be obtained within 10 sec of that response. The present results are consistent with those obtained in Experiments 1 and 2 and, in addition, they show that even when both components are clearly signalled by additional stimuli, animals continue to wait approximately 20 sec following reinforcement on DRL 20-10.

It was noted in Chapter 5 that when reinforcement rate and response rate in the t_2 component were reduced by increasing the t_2 requirement, behavioural contrast did not occur in the components of the two-component DRL. These results did not appear to be in agreement with previous reports of behavioural contrast when reinforcement rate and response rate were reduced in one component of a multiple schedule (e.g., Reynolds 1961; Terrace, 1966). Contrast is usually established on multiple schedules which provide continuous stimuli signalling the different components (Staddon, 1974 a). It was thought that the absence of such stimuli in the

two-component DRL schedules, may have prevented a
reduction in response rate occurring on t_1, as a
function of the size of the t_2 requirement. However,
the present data showed no decrease in the duration of
IRTs on the t_1 component when stimuli were added to the
schedule components, but rather it was indicated that
additional stimuli contributed little to existing
stimulus control on these schedules.

It seems, therefore, that the differences on two-
component schedules and conventional multiple schedules
may lie in the relationship between the subject's
behaviour and the presentation of the schedule components.
In the two-component schedule the occurrence of the t_2
component is contingent upon performance in the t_1
component;   increasing the duration of the t_2 requirement
may thus serve to decrease, rather than increase, response
rate in t_1 as shorter IRTs produce a more unfavourable
consequence   (see Chapter 5). Such contingency
relationships are absent from conventional multiple
schedules in which components are in operation for a
predetermined period of time, or a preset number of
reinforcements.

EXPERIMENT 4

Considerable evidence has been presented so far which indicates that the reinforcer on two-component DRL schedules has stimulus properties. When the IRT requirement has been met on either the t_1 or the t_2 component the reinforcer is usually followed by an IRT approximating the t_1 criterion. Although it seems likely that the reinforcer is the stimulus controlling these IRTs, it is also possible, as suggested by Angle (1970), that IRTs themselves may enter into the determination of subsequent IRTs. Thus the IRTs which follow successful t_2 responses may not be controlled by the preceding reinforcer but by the duration of the preceding IRT. For example, on DRL 20-30 a response on the t_2 component which meets the t_2 criterion is reinforced and is in turn usually followed by an IRT which approximates the 20-sec t_1 requirement. This latter IRT is preceded by (i) the reinforcer, and (ii) an IRT which exceeds 30 sec. Either of these may enter into the determination of the subsequent IRT. Thus, if the duration of the prior IRT functions as a discriminative stimulus, then when reinforcement is omitted from a response which meets the t_2 requirement the following IRT may still approximate the t_1 criterion.

The present experiment tested this possibility.
Reinforcement was omitted following IRTs which met
the IRT criterion in the t_2 component, over a range
of two-component schedules.

Subjects

Seven male albino rats (101, 102, 104, 106, 109,
140, 144) served as subjects. Animals 102, 109, 140
and 144 were experimentally naive at the start of the
experiment. Animals 101 and 104 had previously served
as subjects in Experiment 3 and Animal 106 in Experiment 1.

Procedure

Following lever training, the four naive subjects
were placed on one of the pairs of schedule parameters
in daily 1-hour sessions. These four subjects were
given a minimum of 40 sessions on a standard two-component
DRL schedule to establish stable performance before
beginning the reinforcement omission phase. Animals 106,
101, and 104, having achieved stable performance on two-
component schedules (see Experiments I and 3) were
placed directly onto the omission condition of the present
experiment. The values of the schedules used and the
number of sessions on each condition are shown for each
subject in Table 6.

TABLE 6

Order of exposure to the experimental conditions
(listed left to right) and the number of sessions
on each condition, for individual subjects.

SUBJECT	SCHEDULE (sec) t_1 t_2	BASELINE SESSIONS	OMISSION SESSIONS
101	20 - 10	105	32
140	20 - 10	40	30
109	20 - 20	42	32
144	20 - 20	40	31
102	20 - 30	44	33
104	20 - 40	107	33
106	20 - 60	65	34

The reinforcement omission phase was identical to the baseline condition except that all reinforcers which previously would have followed IRTs which met the DRL criterion on the t_2 component were now omitted. All subjects were given a minimum of 30 sessions on this condition to allow performance to become stable.

For all subjects experimental conditions were altered or terminated when the formal stability criterion was met and visual inspection of the records showed that responding was stable.

Results

The frequency distributions for each subject were obtained (i) from the final two sessions on the baseline condition, (ii) from the first session in which reinforcement was omitted from the t_2 component, and (iii) from the final two sessions on the omission condition. In all cases distribution of IRTs on the t_1 and t_2 components as well as the overall frequency distributions are presented. IRT distributions following reinforced responses (referred to as "t+") and following non-reinforced responses (referred to as "t-") are also shown; on the omission conditions IRTs on the t_1

component sometimes followed non-reinforced responses.
The t_1 and t_2 distributions on the baseline condition
were, of course, the same as the distributions
following reinforced and non-reinforced responses,
respectively.

DRL 20-10: The relative frequency distributions of
IRTs are shown in Figure 18 for Animal 101 and in
Figure 19 for Animal 140, both of which were on
DRL 20-10; the overall distributions are not shown in
these figures but are presented separately in the
Appendix (Figures 65, 66). Responding on the baseline
schedule was typical of that previously observed in
Experiments 1-3 on DRL 20-10, with IRTs on t_1 and t_2
matching, approximately, the IRT requirement on each
component. Bursts were present only on t_2.

The shape of the distributions in the first
omission session, particularly on the t_1 component
differed considerably from that observed on the baseline
conditions. For Animal 101 (Figure 18) the great
proportion of the IRTs occurring on the t_1 component no
longer approximated the 20-sec t_1 requirement but
resembled more the distribution which occurred on t_2;
there was a peak in the shortest IRT class interval. A

Figure 18. Relative frequency distributions of IRTs for Animal 101 from (i) the final two sessions on DRL 20-10 (baseline), (ii) the first session in which reinforcement was omitted from the t_2 component (first omission), (iii) the final two sessions on the omission condition (final omission). The frequencies are shown separately for the t_1 and t_2 components and, in the case of the omission conditions, following reinforced (t_+) and non-reinforced (t_-) responses.
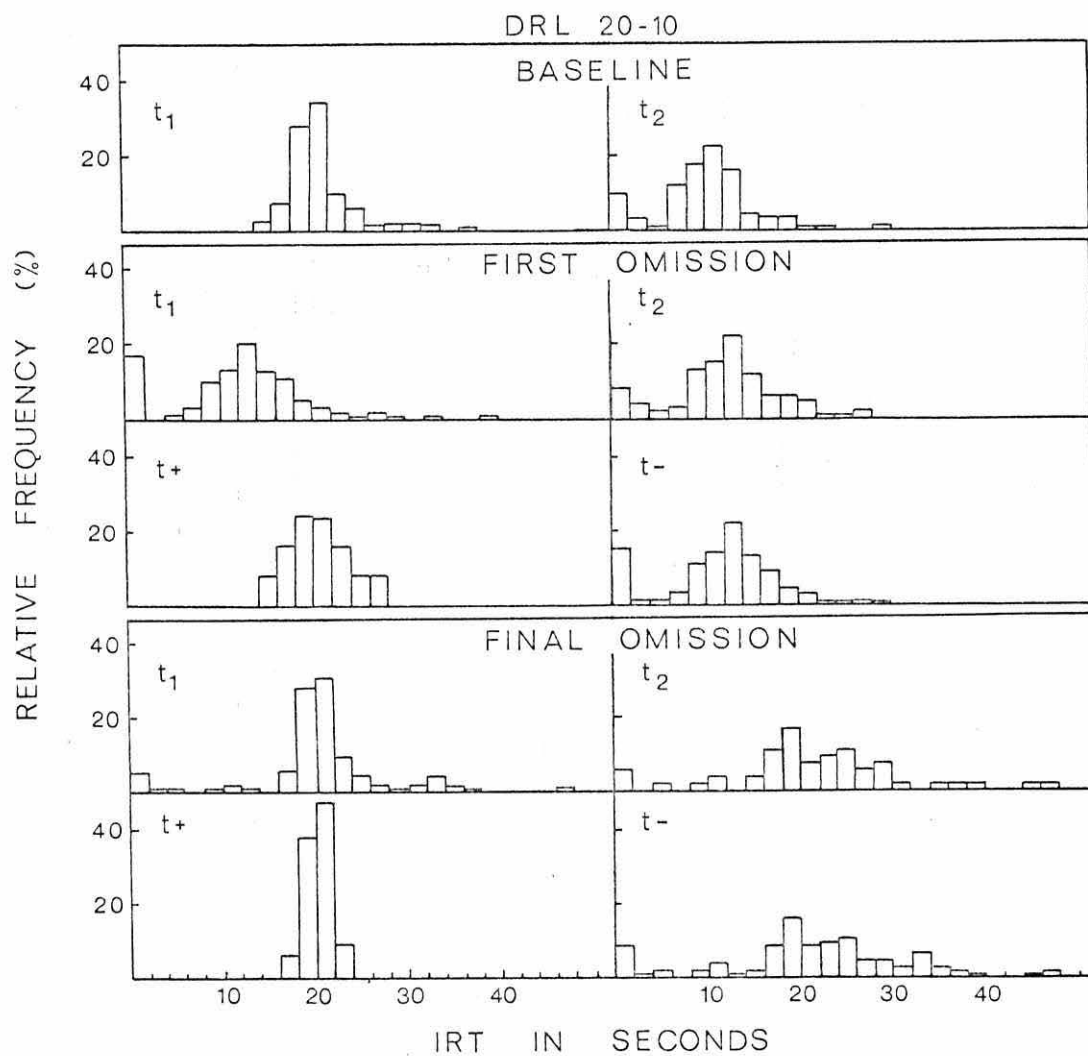
DRL 20-10

Figure 19. Relative frequency
distributions of IRTs for Animal
140 from (i) the final two sessions on
DRL 20-10 (baseline), (ii) the first
session in which reinforcement was omitted
from the t_2 component (first omission),
(iii) the final two sessions on the
omission condition (final omission). The
frequencies are shown separately for the
t_1 and t_2 components and, in the case of
the omission conditions, following reinforced
(t_+) and non-reinforced (t_-) responses.

DRL   20-10
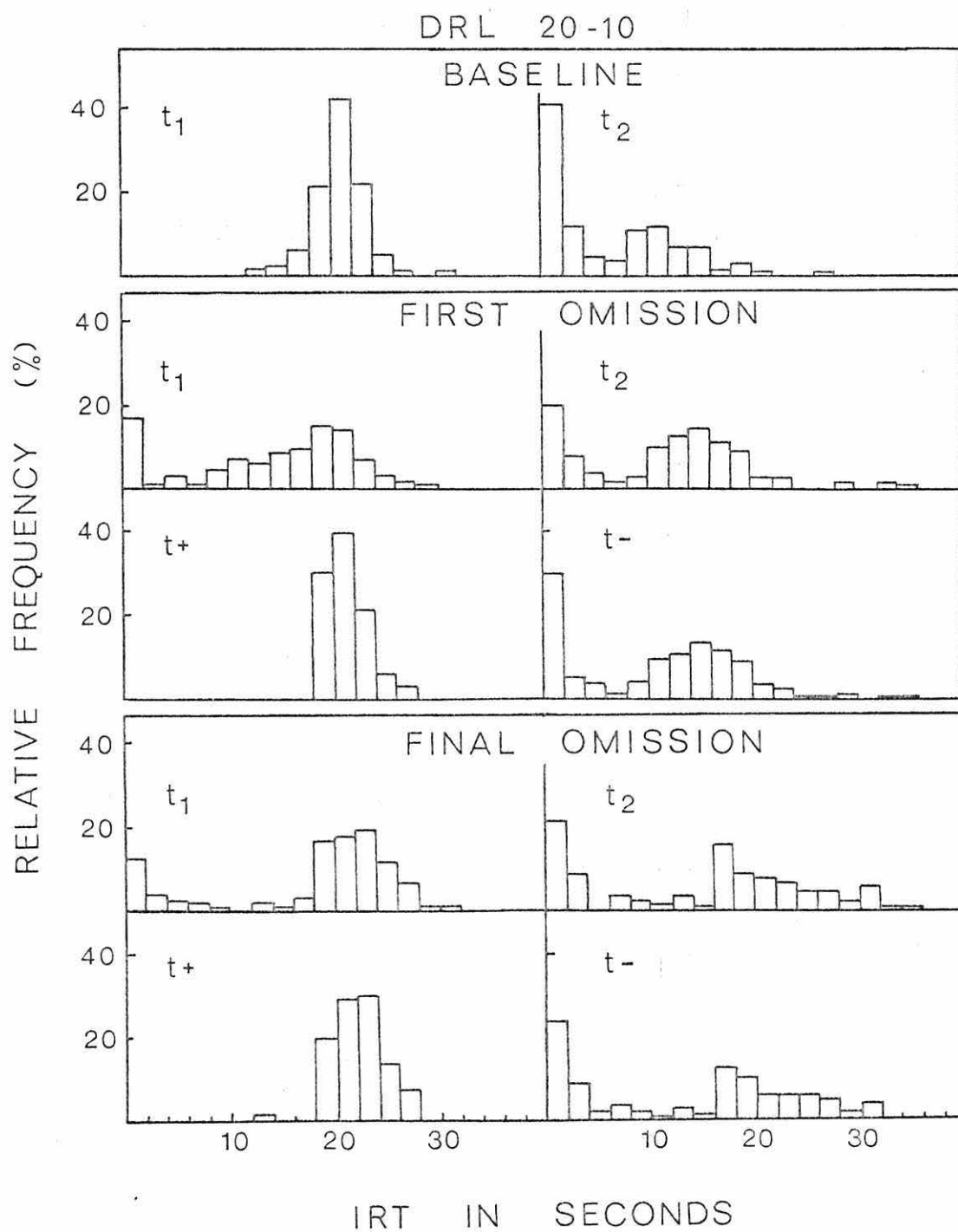
shift toward shorter IRTs was also evident in the t_1
distribution for Animal 140 and bursts were again
present on the t_1 component.

Two-component control appears to have been
diminished, in the first session of reinforcement
omission; IRTs on the t_1 component, most often,
failed to meet the t_1 requirement. However, when those
IRTs on t_1 which were preceded by reinforcement were
considered, control by the t_1 requirement was apparent.
The distribution of IRTs, following reinforcement, when,
of course, the t_1 contingency was in effect, peaked in
the region of the 20-sec class interval for both subjects.
In the t_1 component there were no bursts in the
distribution of those IRTs which were preceded by
reinforcement. Following non-reinforced responses on
the other hand the distribution of IRTs was very similar
to that which occurred on the t_2 component.

The general pattern of behaviour on the first
omission session may then be described as follows: when
the subjects were on the t_2 component, IRTs were appropriate
to the 10-sec requirement and the distribution was similar
to that which occurred on the baseline schedule; when an

IRT met the t_2 criterion, but went unreinforced, the next IRT was usually similar in duration to the IRTs which occurred in the t_2 component; it was either a burst or in the region of 10-16 sec. When an IRT met the t_1 criterion and was reinforced, it was likely to be followed by an IRT which approximated the t_1 requirement.

Whereas in the first omission session most IRTs which occurred approximated the t_2 requirement in the final omission sessions most IRTs were in the region of 20 sec or longer. This was true of distributions both on the t_1 and on the t_2 components (Figures 18 and 19). Bursts contined to appear on the t_1 component, though with a lower frequency than in the first omission session. The distributions following reinforced and non-reinforced responses show that after reinforced responses on t_1, IRTs were peaked around the 20-sec class interval and bursts were absent. IRTs after non-reinforced responses were either bursts or were approximately 20 sec or longer.

Figure 20 shows sequences of IRTs for Animals
101 and 140, giving the first three occasions on
which the contingency switched from t_1 to t_2: (i) in
the final session of the baseline condition, (ii) in
the first session of reinforcement omission, and (iii)
in the final omission session. In the baseline
condition, IRTs after reinforcement (on t_1) approximated
the t_1 requirement, whereas following a non-reinforced
response (on t_2) there was either a burst or an IRT
in the region of 10 sec.

In the first omission session the pattern of
responding was similar to that on the baseline
condition if the IRTs are classified as those following
reinforced and non-reinforced responses, but not when
they are classified with regard to the component in
operation. In the case of Animal 101, for example,
the first non-reinforced response following reinforcement
was just short of the 20-sec requirement. This was
followed by a burst which was in turn followed by an
IRT which just exceeded the 10-sec t_2 requirement. So
far the pattern of responding was very similar to that
shown on the baseline conditions. However, after an
IRT which put the t_1 contingency into effect, but which
went unreinforced, the next IRT approximated the t_2

Figure 20. Sequences of IRTs from
Animals 101 and 140, on DRL 20-10,
which show the transition from the t_1
to the t_2 contingency and, depending
on whichever occurred first, either
(a) all subsequent IRTs until an IRT
was reinforced and two further IRTs, or
(b) six successive non-reinforced IRTs.
The first three such sequences are
shown from the final session on the
baseline condition and from the first
and final sessions on the omission condition.
Filled circles indicate IRTs which were
reinforced. Open circles indicate non-reinforced
IRTs.
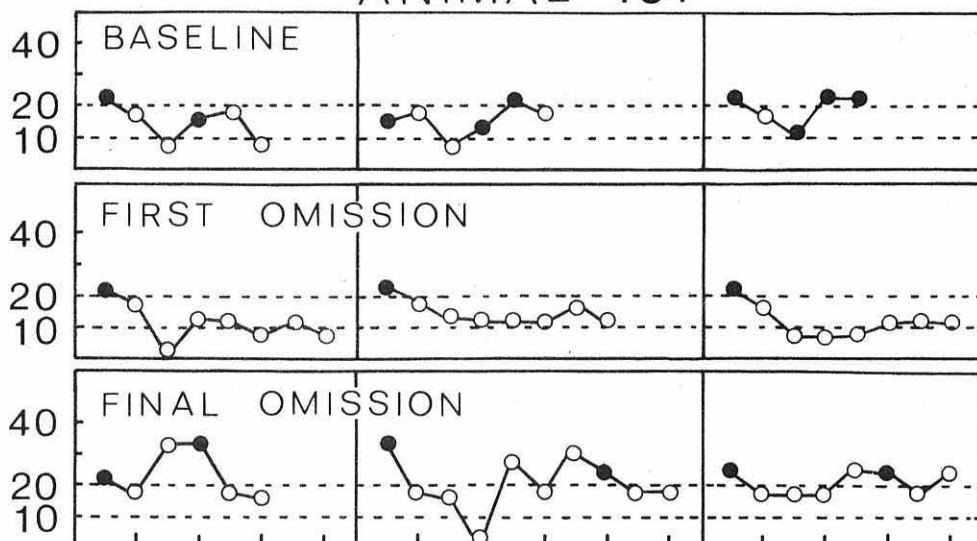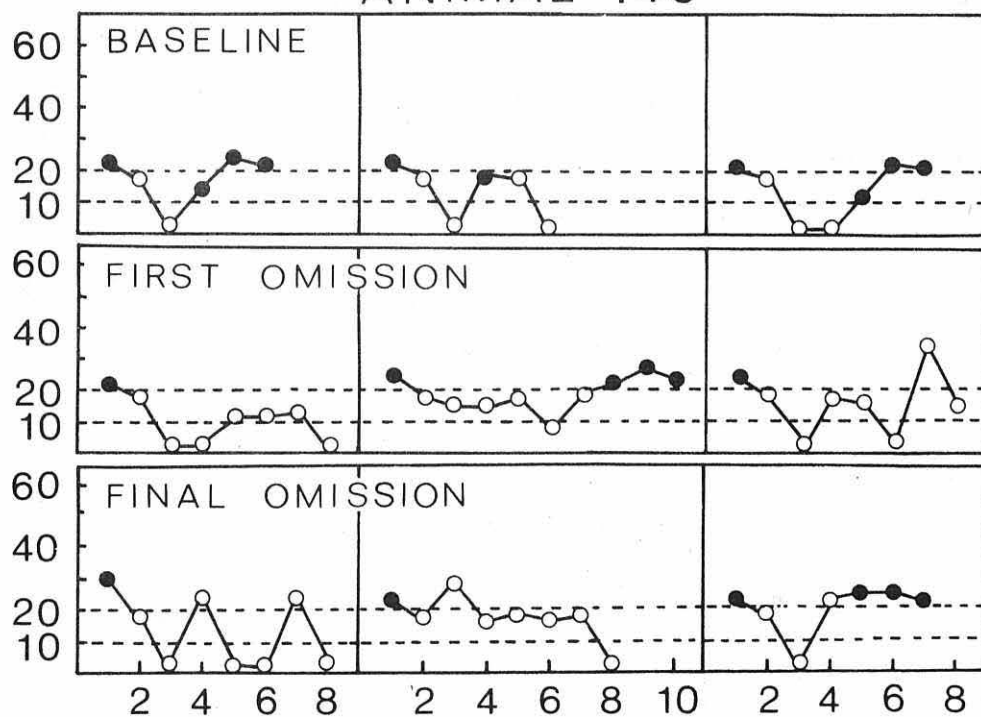
criterion, as indeed did the three subsequent IRTs.
This is similar to the baseline performance insofar
as non-reinforced IRTs were followed either by
bursts or by IRTs close to 10 sec. There is a
dissimilarity in that IRTs, having met the t_2
requirement, were followed by IRTs appropriate to t_2
but not to the t_1 criterion, which was in effect at
the time. This control by non-reinforced responses
of 10-sec IRTs is also evident in the remaining two
sequences shown for Animal 101 on the first-omission
session. The IRT sequences for Animal 140 on the
first session of reinforcement omission are in general
similar to those for Animal 101.

The sequences from the final omission session, for
both subjects, show changes in performance, particularly
with respect to non-reinforced responses. Following
reinforcement IRTs were close to the 20-sec t_1
requirement; IRTs after non-reinforced responses,
regardless of which component was in effect, were either
bursts or were about 20 sec or longer.

DRL 20-20: The data from the two subjects, 109 and 144,
on DRL 20-20 are similar in many respects to those
obtained from the DRL 20-10 animals. The frequency

distributions for these two subjects, 109 and 144, are shown in Figures 21 and 22 respectively; overall distributions are presented in the Appendix (Figures 67, 68). They show that, on the first session, when reinforcement was omitted from t_2, response bursts appeared on the t_1 component. These bursts, however, only occurred following non-reinforced responses; following reinforced responses bursts were absent. On the final omission session the frequency of bursts in the t_1 component was greatly reduced for both subjects.

The IRT sequences are shown in Figure 23. The relationships observed above, particularly the occurrence of bursts following non-reinforced responses on the t_1 component, were also observed in the IRT sequences.

DRL 20-30, DRL 20-40 and DRL 20-60: The IRT frequency distributions from the three subjects on schedules where the t_2 value was longer than that of t_1, are shown in Figures 24, 25, 26, for Animal 102 (DRL 20-30), Animal 104 (DRL 20-40) and Animal 106 (DRL 20-60), respectively. Corresponding overall distributions are presented separately in the Appendix (Figures 69, 70,
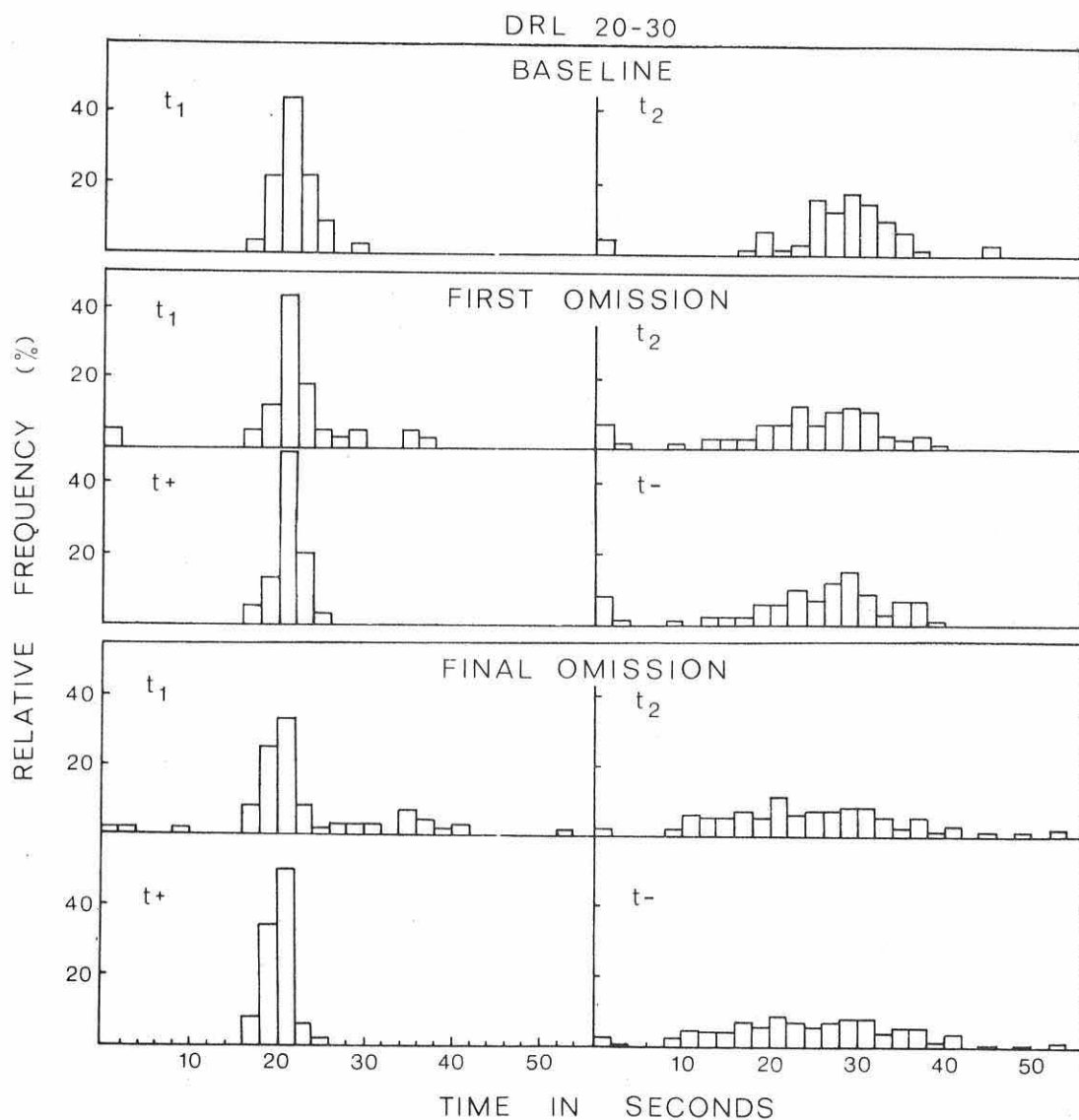
Figure 21. Relative frequency
distributions of IRTs for Animal
109 from (i) the final two sessions
on DRL 20-20 (baseline), (ii) the first
session in which reinforcement was
omitted from the t_2 component (first
omission), (iii) the final two sessions
on the omission condition (final omission).
The frequencies are shown separately for
the t_1 and t_2 components and, in the case
of the omission conditions, following
reinforced (t_+) and non-reinforced (t_-)
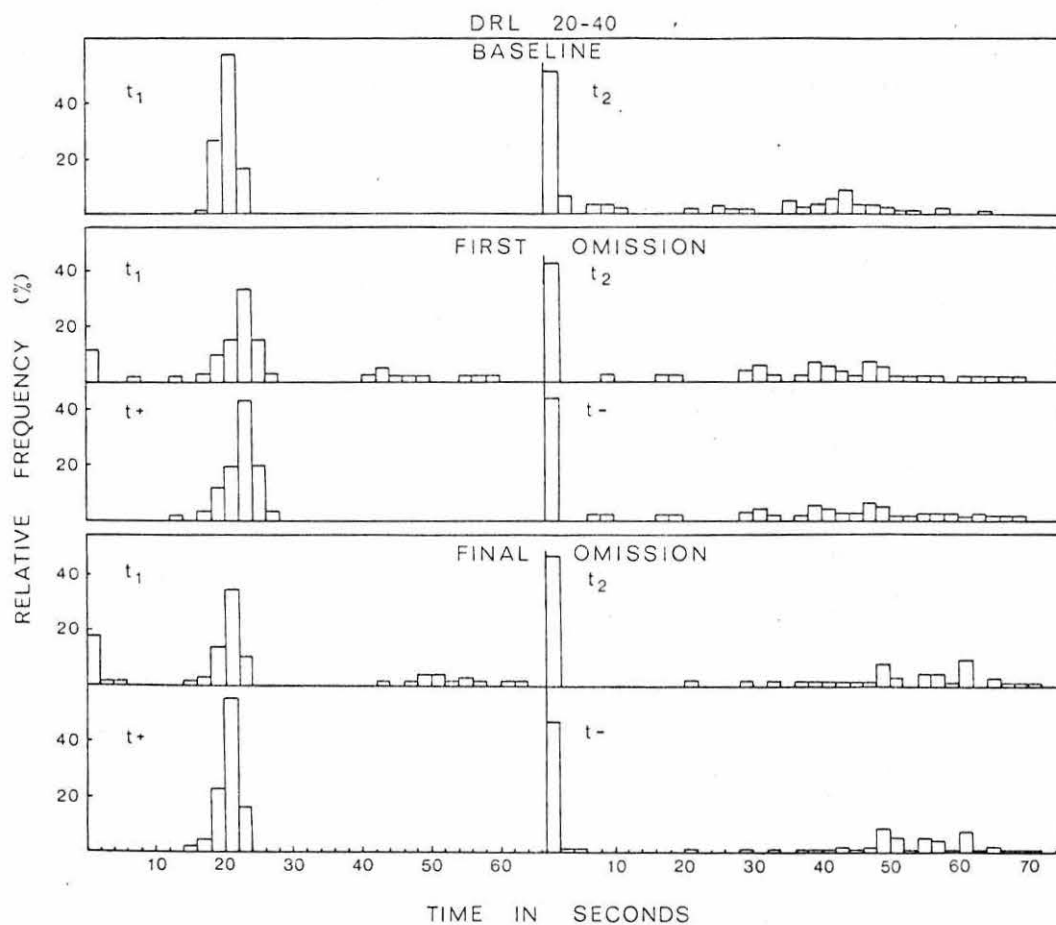responses.
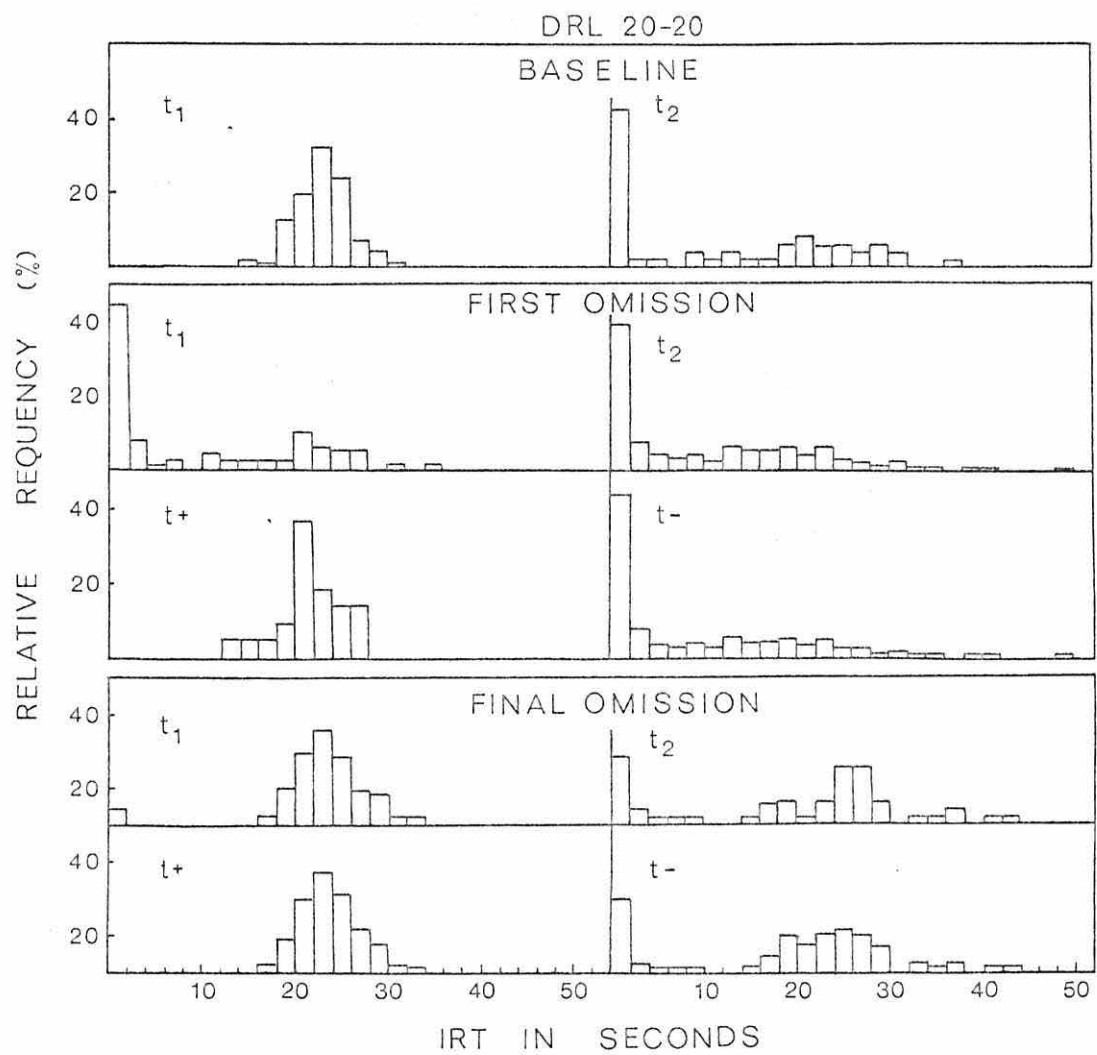
DRL 20-20

Figure 22. Relative frequency
distributions of IRTs for Animal
144 from (i) the final two sessions
on DRL 20-20 (baseline), (ii) the
first session in which reinforcement
was omitted from the t_2 component (first
omission), (iii) the final two sessions
on the omission condition (final omission).
The frequencies are shown separately for
the t_1 and t_2 components and, in the case
of the omission conditions, following
reinforced (t_+) and non-reinforced (t_-)
responses.

DRL 20-20

Figure 23. Sequences of IRTs from
Animals 109 and 144, on DRL 20-20,
which show the transition from the
t_1 to the t_2 contingency and, depending
on whichever occurred first, either (a)
all subsequent IRTs until an IRT was
reinforced and two further IRTs, or
(b) six successive non-reinforced IRTs.
The first three such sequences are shown
from the final sessions on the baseline
condition and from the first and final
session on the omission condition.

ANIMAL 109

DURATION IN SECONDS

BASELINE
FIRST OMISSION
FINAL OMISSION

ANIMAL 144

BASELINE
FIRST OMISSION
FINAL OMISSION
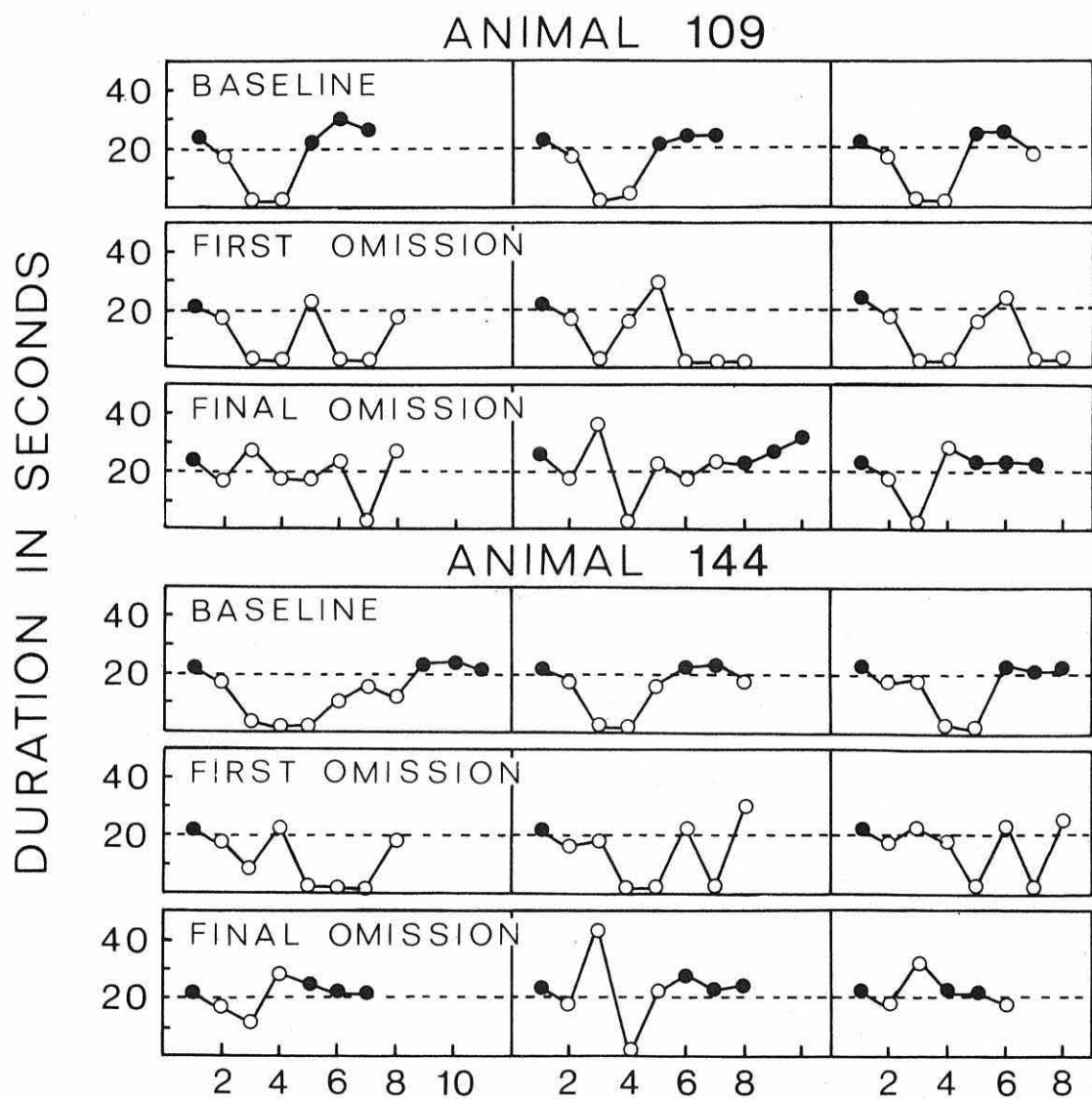
SUCCESSIVE INTER-RESPONSE TIMES

Figure 24. Relative frequency
distributions of IRTs for Animal
102 from (i) the final two sessions
on DRL 20-30 (baseline), (ii) the
first session in which reinforcement
was omitted from the t_2 component
(first omission) (iii) the final two
sessions on the omission condition
(final omission). The frequencies
are shown separately for the t_1 and t_2
components, and, in the case of the
omission conditions, following
reinforced (t+) and non-reinforced (t-)
responses.

DRL 20-30

Figure 25. Relative frequency
distribution of IRTs for Animal
104 from (i) the final two sessions
on DRL 20-40 (baseline), (ii) the
first session in which reinforcement
was omitted from the t_2 component
(first omission) (iii) the final two
sessions on the omission condition
(final omission). The frequencies
are shown separately for the t_1 and t_2
components and, in the case of the
omission conditions, following reinforced
(t_+) and non-reinforced (t_-) responses.

Figure 26. Relative frequency
distributions of IRTs for Animal
106 from (i) the final two sessions
on DRL 20-60 (baseline), (ii) the
first session in which reinforcement
was omitted from the t_2 component
(first omission), (iii) the final two
sessions on the omission condition
(final omission). The frequencies
are shown separately for the t_1 and t_2
components and, in the case of the
omission conditions, following reinforced
(t_+) and non-reinforced (t_-) responses.
IRTs longer than 78 sec are contained in the
final IRT category of each distribution.

DRL 20-60
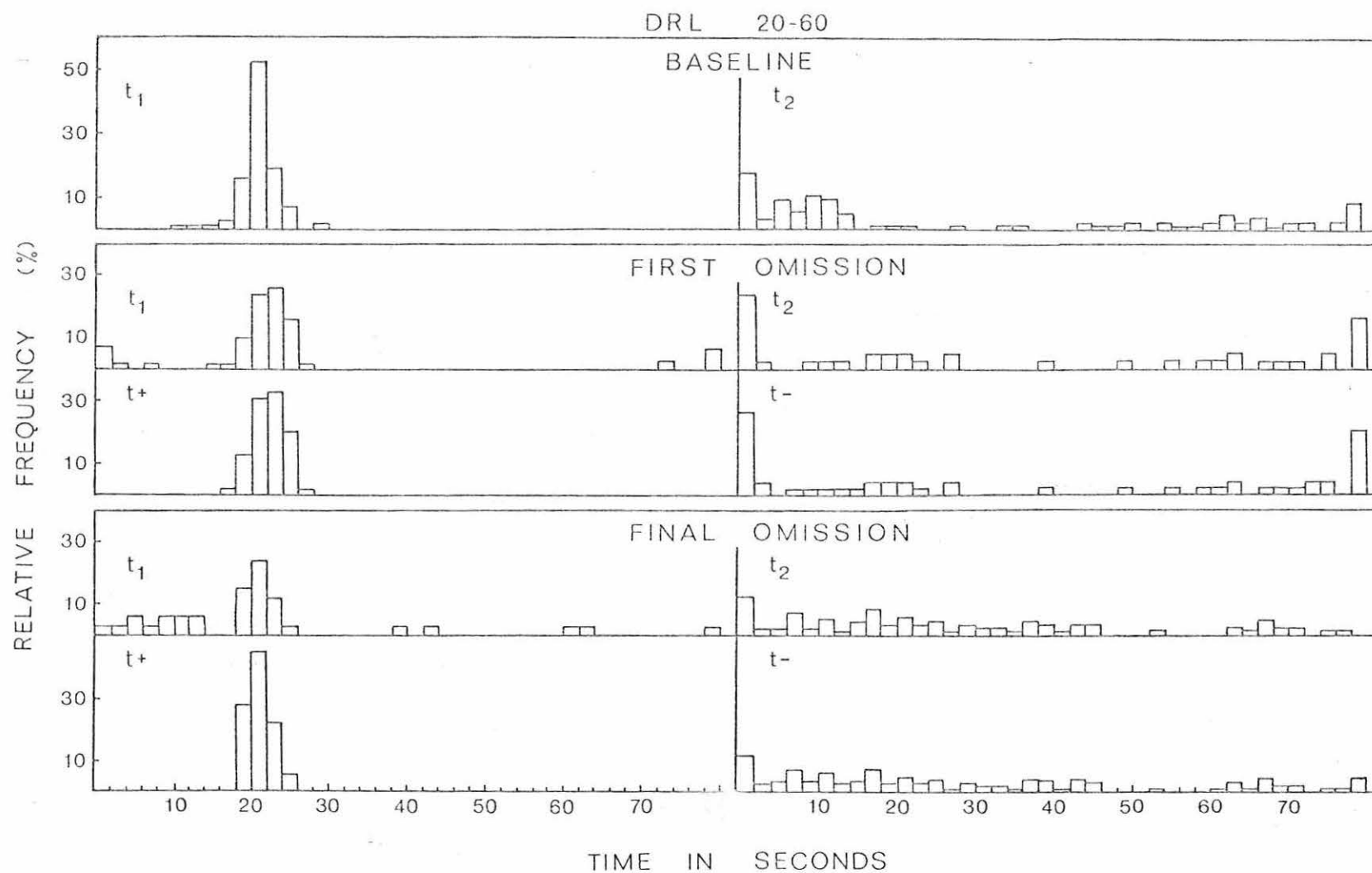
71). Again there are similarities with the performance
of the DRL 20-10 subjects. On the first omission
session, bursts appeared on the t_1 component and IRTs
longer than 20 sec, which only occurred in the t_2
component on the baseline condition, were here also in
evidence on t_1. The distribution of IRTs that were
preceded by reinforcement, on the other hand, peaked
in the region of 20 sec and contained no IRTs which
either approximated the longer t_2 requirement or were
bursts.

Longer IRTs appropriate to the t_2 contingency,
and bursts, continued to occur in the final sessions
of the omission condition, though, as was the case
with the DRL 20-10 and DRL 20-20 subjects, the frequency
of bursts on t_1 was reduced. One exception to this
was Animal 104 which produced a slightly higher
proportion of bursts in the final omission sessions than
in the first omission session. The IRTs in the t_2
component were similar to those occurring in this
component on the baseline condition and on the first
omission session, though showing greater variability.
The sharp differentiation in IRTs following reinforced
and non-reinforced responses, in baseline and first
omission sessions, was also present in the final sessions
of reinforcement omission.

The IRT sequences are shown in Figure 27 for Animals 102 and 104, while those for Animal 106 are shown in Figure 28. On the first omission session the control by reinforcement of IRTs of approximately 20 sec is clearly evident and following non-reinforcement IRTs were most often either bursts or were appropriate to the t_2 requirement. There were instances here of the animal meeting the t_2 requirement by emitting a long IRT and then emitting a long IRT more appropriate to the t_2 component rather than an IRT of 20 sec which would have been sufficient to produce reinforcement. This pattern of behaviour persisted in the final omission session; the animals did not learn to make 20 sec IRTs following IRTs which met the t_2 requirement but went unreinforced.

For all three subjects on the omission conditions, IRTs which matched the requirements of both components continued to occur but they were not well correlated with the components in operation; rather, following reinforcement IRTs occurred which approximated the t_1 criterion, while following non-reinforced responses IRTs occurred which were appropriate to the t_2 requirement, regardless of which component was in effect.

Figure 27. Sequences of IRTs from Animals 102 and 104, on DRL 20-30 and DRL 20-40 respectively, which show the transition from the t_1 to the t_2 contingency and, depending on whichever occurred first, either (a) all subsequent IRTs until an IRT was reinforced and two further IRTs, or (b) six successive non-reinforced IRTs. The first three such sequences are shown from the final session on the baseline condition and from the first and final sessions on the omission condition.

ANIMAL 102

ANIMAL 104

DURATION IN SECONDS
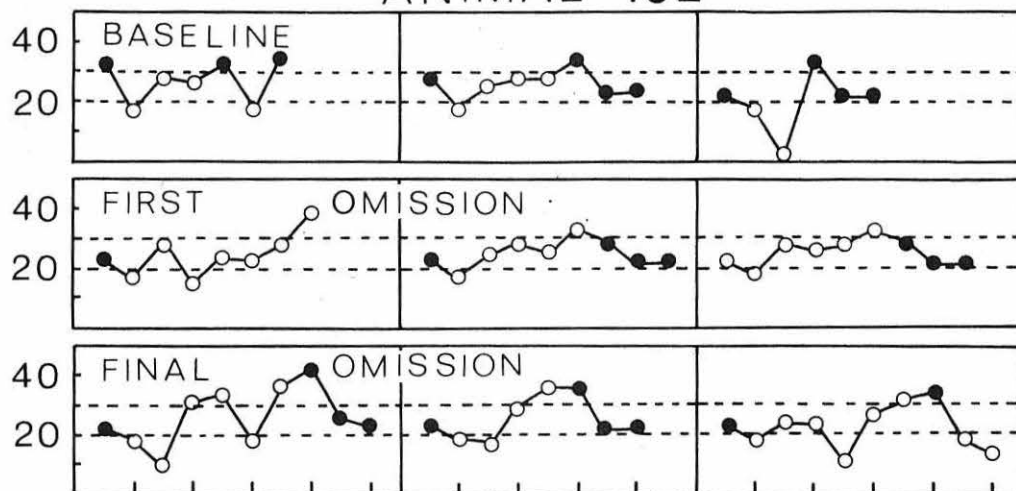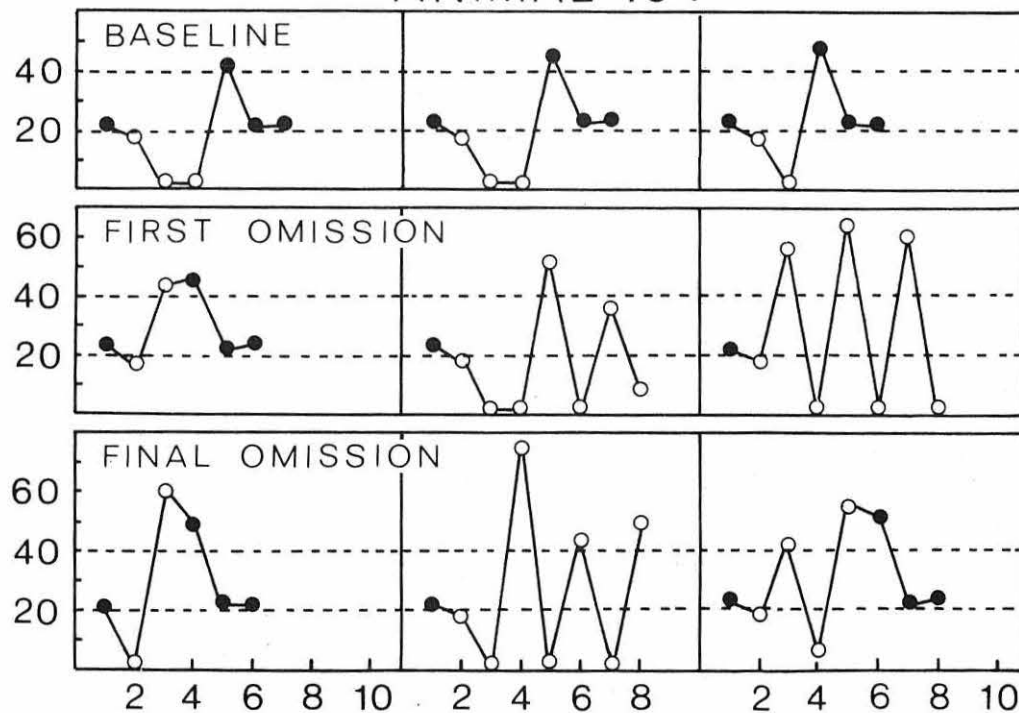
SUCCESSIVE INTER-RESPONSE TIMES

Figure 28. Sequences of IRTs
from Animal 106 on DRL 20-60, which
show the transition from the t_1 to
the t_2 contingency and, depending
on whichever occurred first, either
(a) all subsequent IRTs until an IRT
was reinforced and two further IRTs,
or (b) six successive non-reinforced
IRTs. The first three such sequences
are shown from the final session on
the baseline condition and from the
first and final sessionson the omission
condition.

DRL 20-60
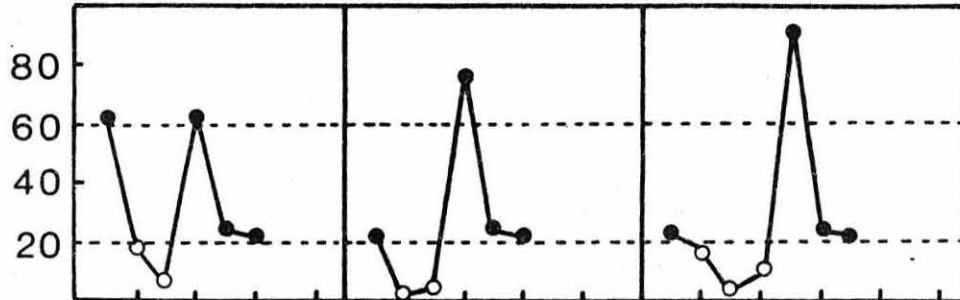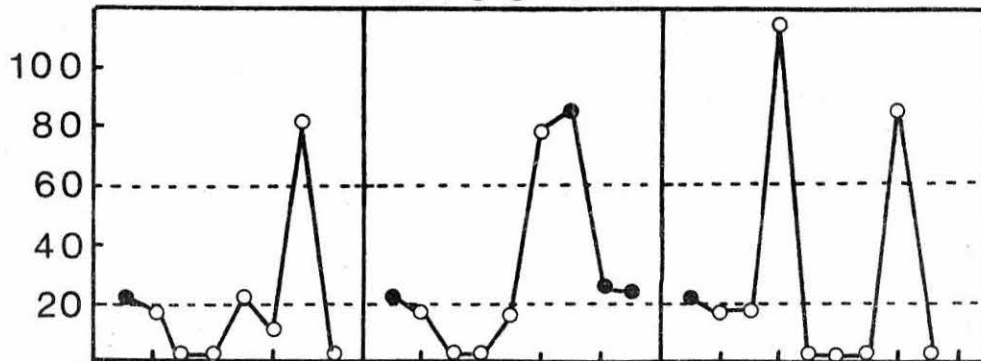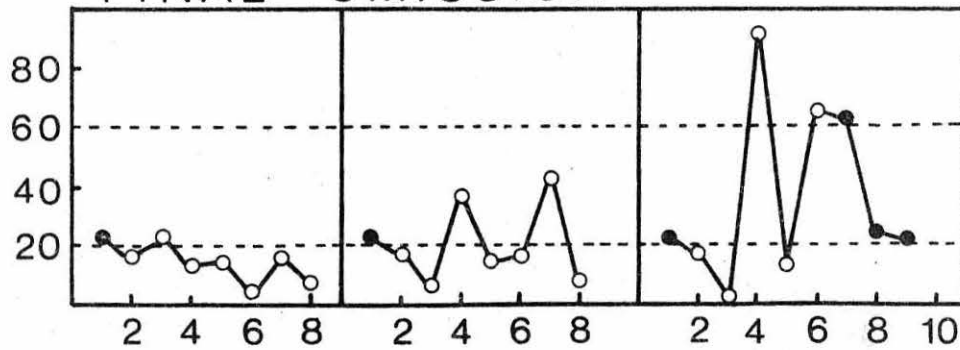
Figure 29 shows the conditional probability* of a burst following those IRTs which met the DRL criterion on t_2 but went unreinforced. The data were taken from the first and final omission sessions. The corresponding data from the baseline condition are not shown, as all IRTs which met the t_2 criterion were reinforced and thus the probability of a burst was always zero. In all cases there was a substantial increase in burst probability beyond the zero level, when reinforcement was first omitted from t_2. There was also for each subject a decline in burst probability with continued exposure to the omission conditions.

Discussion

The results of the present experiment show that on two-component DRL schedules in which t_1 and t_2 are not of equal duration, when the reinforcing stimulus is first omitted from the t_2 component, differential control by both components is diminished. When an IRT long enough to meet the t_2 criterion occurred on t_2 the following IRT was most often not appropriate to the t_1 requirement but the subjects behaved as if they were still on t_2. This indicates that the stimuli which control IRTs appropriate to both components of the two-

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* Calculated by dividing the number of times a burst followed an IRT which met the requirement on t_2 by the total number of such IRTs.

Figure 29. The conditional probability of a burst following IRTs which met the DRL criterion on the t_2 component, in the first session of the omission condition (open bars) and in the final omission session (filled bars). Data are shown for each subject on each schedule.
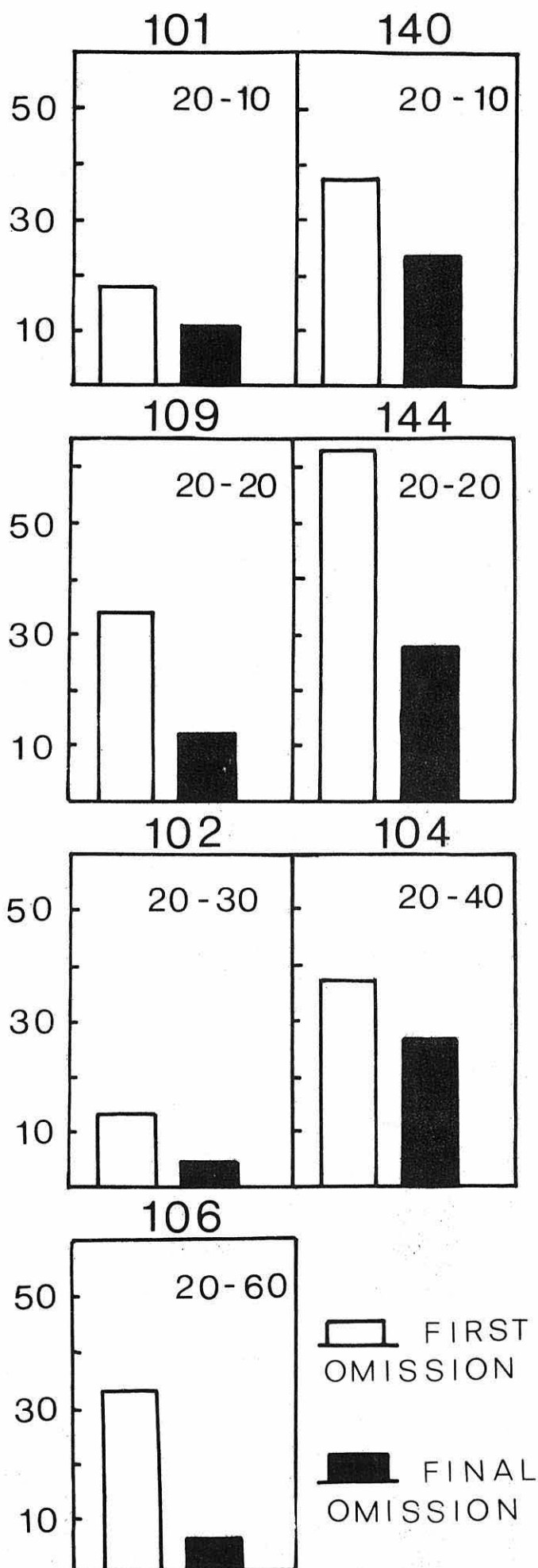
component schedules are reinforced and non-reinforced responses, rather than the duration of the preceding IRT.

When the omission condition was continued until responding reached stability, performance on schedules where t_2 was longer than t_1 differed from performance on schedules in which t_2 was shorter than t_1. In neither case was there any evidence that the t_1 requirement was discriminated on the basis of the duration of the preceding IRT in t_2. For example, those subjects on the longer t_2 values continued to respond as if the t_2 component were in operation following all non-reinforced responses, regardless of the duration of the preceding IRT.

If this strategy had been adopted by the subjects on DRL 20-10 then very few reinforcements would have been produced as IRTs would not have been long enough to meet the 20-sec requirement of t_1. On the first session of reinforcement omission there were many IRTs which went unreinforced and were then followed by IRTs which were more appropriate to the 10-sec requirement of t_2, than to the 20-sec requirement of t_1. By the final

omission sessions, however, the subjects emitted IRTs of approximately 20 sec or bursts following all non-reinforced responses; the discrimination of the 10-sec t_2 requirement was lost.

These results show that the duration of the preceding IRT had little or no controlling influence on the subsequent IRT emitted and that, even with extended exposure to the omission condition, the effective controlling stimuli were reinforced and non-reinforced responses.

The suggestion that bursts on DRL are a function of the frustrative effect of non-reinforcement (see Chapter 5) received further support. When reinforcement was omitted from responses which met the t_2 requirement response bursts occurred, whereas previously when reinforcement had been presented for these responses, bursts had been absent. This increase in the frequency of bursts following reinforcement omission is consistent with the results of Caplan (1970) who found that, when reinforcements were omitted on a conventional DRL schedule, the overall frequency of bursts increased.

In the first session in which reinforcement was omitted from the t_2 component the expectancy of reinforcement would have been high following IRTs on

the t_2 component. When these IRTs went unreinforced frustration should have been considerable. However, on the final omission sessions, as the subjects had by then experienced a lowered frequency of reinforcement, expectancy should consequently have been lower. Reinforcement omission in the final sessions should thus have produced a weaker frustration effect and fewer response bursts, than when reinforcement was first omitted. This was found to be the case for each subject in the present experiment; the probability of a response which met the t_2 requirement, but went unreinforced, being followed by a burst, declined with extended exposure to the omission condition.

EXPERIMENT 5

This experiment investigated the effects of reinforcement omission in the t_1 component of DRL schedules. All reinforcements were omitted following the first response to occur after reinforcement. The omission condition was not strictly equivalent to the two-component DRL schedules employed previously, as in this case there was no IRT requirement in effect following

reinforcement. The schedule may thus be described
as a response-initiated DRL schedule, or tandem
FR 1 DRL (tand FR 1 DRL), comparable to the response-
initiated fixed-interval (tand FR 1 FI) schedules used
in other studies (Neuringer and Chung, 1967; Shull,
1970 a) and to the two-lever response-initiated DRL
schedule employed by Mechner and Guevrekian (1962).

Subjects

Two experimentally naive male albino rats (112
and 114) served as subjects.

Procedure

Following lever training, Animal 112 was placed
on DRL 10-10 and Animal 114 on DRL 20-20. Both subjects
were given a minimum of 40 sessions on these schedules.
When responding was stable the omission phase was
begun; the first response after every reinforcement
went unreinforced and initiated either the 10-sec
requirement (Animal 112) or the 20-sec requirement
(Animal 114).

The conditions were then altered so that each
component of the schedule was accompanied by a differential
stimulus. For Animal 112 the panel lights were switched
on when reinforcement occurred and remained on until the

DRL was initiated by the next response; this in turn caused the lights to be switched off until the next reinforcement. The panel lights came on, for Animal 114, when the first response occurred after reinforcement and remained on until reinforcement occurred.

The additional stimuli were removed in the next experimental condition so that the conditions prevailing during the second phase were restored.

The final condition consisted of a return to the original DRL schedules. The sequence of conditions for each subject and the number of sessions in each condition are shown in Table 7. Both subjects were given a minimum of 20 sessions on each condition, after the first phase, to allow responding to become stable. Experimental conditions were altered or terminated when the formal stability criterion was met and visual inspection of the records showed that responding was stable.

Results

The relative frequency distributions of IRTs following reinforcement (t+) and following non-reinforced responses (t-), obtained in the last two sessions on each condition, are shown in Figure 30 for Animal 112. Corresponding

TABLE 7

Order of exposure to the experimental conditions
(listed top to bottom) and the number of sessions
on each condition, for individual subjects

SUBJECT	SCHEDULE (SEC)		SESSIONS
	DRL 10 — 10		40
	FR 1	DRL 10	20
112	FR 1^{+light}	DRL 10	21
	FR 1	DRL 10	21
	DRL 10 — 10		20
	DRL 20 — 20		42
	FR 1	DRL 20	20
114	FR 1	DRL 20^{+light}	21
	FR 1	DRL 20	22
	DRL 20 — 20		20

Figure 30. Relative frequency
distributions of IRTs for Animal
112 following reinforced (t_+) and
non-reinforced (t_-) responses. The
data are from the final two sessions
on each of the five experimental
conditions: (i) DRL 10-10, (ii)
response initiated DRL 10 (FR 1 DRL 10),
(iii) response-initiated DRL 10 with a
stimulus (light) added to IRTs which
followed reinforced responses, (iv)
response-initiated DRL 10 with the
stimulus removed, (v) DRL 10-10.
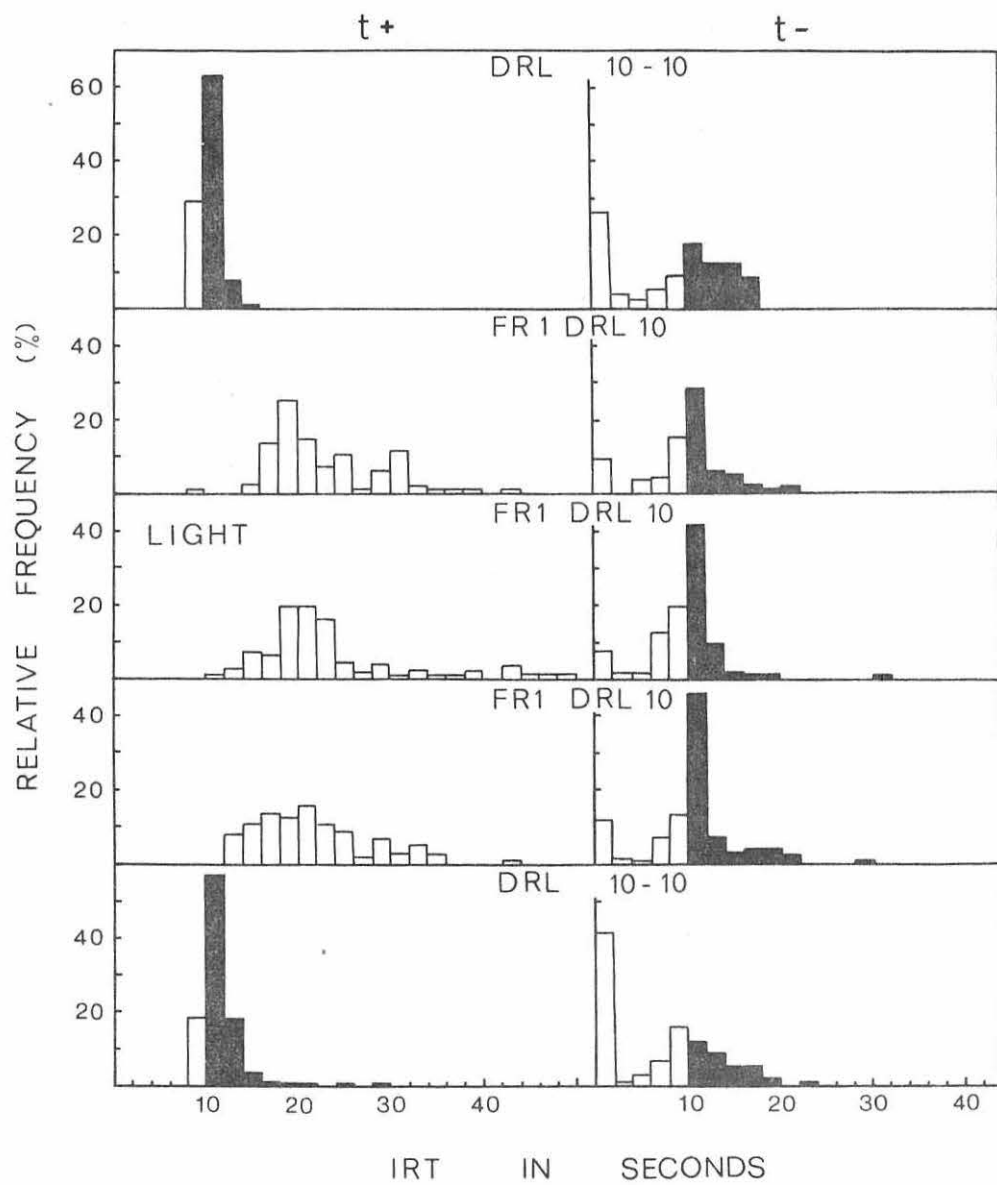
overall distributions are presented in the Appendix
(Figure 72). Figure 30 shows that, on first
exposure to DRL 10-10, IRTs of approximately 10 sec
followed reinforced and non-reinforced responses.
Bursts occurred only after non-reinforced responses.

In the tand FR 1 DRL 10 condition the distribution
of IRTs after non-reinforced responses was similar to
that on DRL 10-10, though the frequency of bursts was
reduced. The distribution of IRTs after reinforced
responses changed markedly and contained much longer
IRTs, peaking in the region of 20 sec. Neither the
addition of the light stimulus following reinforcement
nor the removal of this stimulus made any difference
to the pattern of responding.

When the DRL 10-10 schedule was reinstated the
peak of the distribution following reinforced responses
shifted back to 10 sec. Bursts on the t_2 component
also increased in frequency and in general the
distributions were similar to those obtained during
original exposure to the DRL 10-10 schedule.

Frequency distributions for Animal 112 on the
first session of tand FR 1 DRL 10 are shown in Figure
31. This shows that as early as the first session the
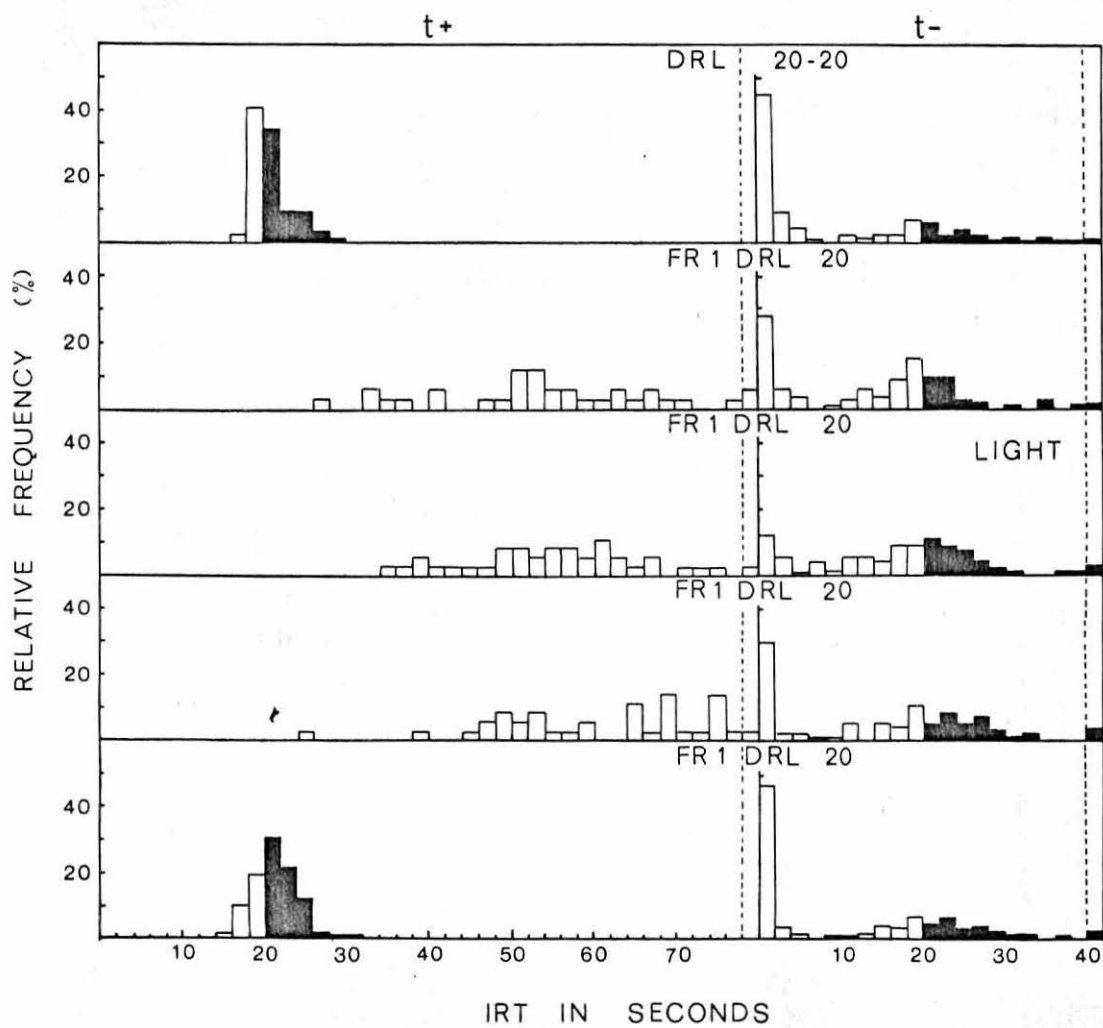shift toward longer IRTs after reinforcement had begun.

Figure 31. Relative frequency
distributions of IRTs for Animal
112 in the first session of
response-initiated DRL 10. The
frequencies are shown separately for
IRTs following reinforced (t+) and non-
reinforced (t-) responses. The
conventional overall frequency
distribution which contains all IRTs
regardless of the components, is also
shown (overall).
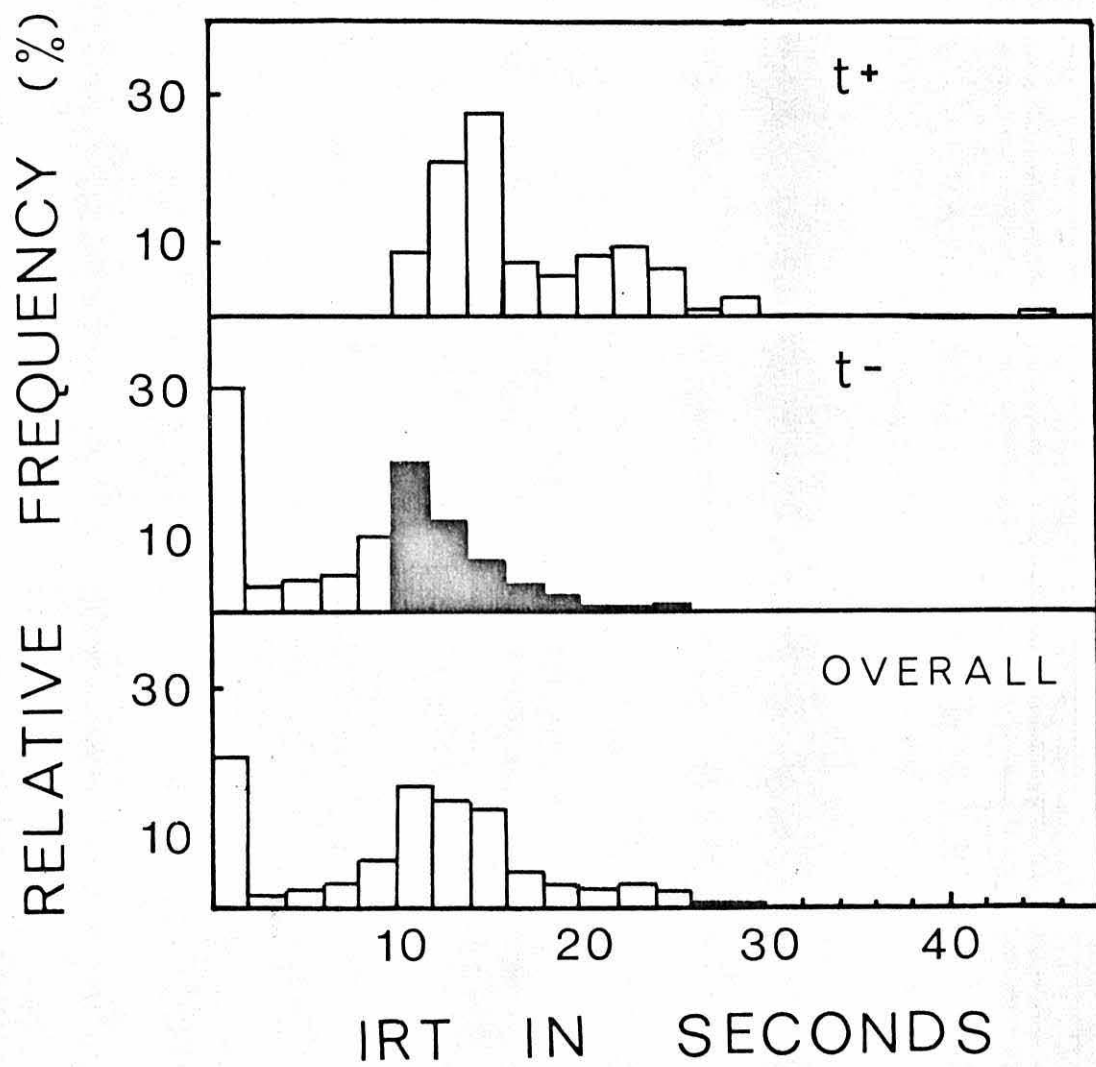
The distributions of IRTs for Animal 114 taken from the last two sessions on each experimental condition are shown in Figure 32. Overall distributions are presented in the Appendix (Figure 73). These data are similar to the data obtained from Animal 112. Performance on tand FR 1 DRL 20 showed much longer IRTs after reinforcement than occurred on DRL 20-20. This persisted when the light stimulus was presented following the first non-reinforced response. The light stimulus had no systematic effect on responding. When the DRL 20-20 contingency was restored the IRT mode following reinforced responses returned to its original position at the 20-sec class interval. Bursts had a lower frequency of occurrence on the tand FR 1 DRL conditions than on DRL 20-20. The distributions from the first session on tand FR 1 DRL 20 (Figure 33) show that most IRTs after reinforcement, occurred in the region of 20 sec, though again there was evidence of longer IRTs beginning to appear.

The changes in the distributions of IRTs which followed reinforcement may be represented by median IRTs and interquartile ranges. These are shown in Figure 34 for both subjects on each experimental condition. The

Figure 32. Relative frequency
distributions of IRTs for Animal
114 following reinforced (t+) and
non-reinforced (t-) responses. The
data are from the final two sessions
on each of the five experiemntal
conditions: (i) DRL 20-20, (ii)
response-initiated DRL 20 (FR1 DRL 20),
(iii) response-initiated DRL 20 with a
stimulus (light) added to IRTs which
followed non-reinforced responses,
(iv) response-initiated DRL 20 with
the stimulus removed, (v) DRL 20-20.
IRTs longer than 78 sec on the t_1
component, and longer than 40 sec on the
t_2 component,are contained in the final
IRT category of their respective
distributions.

t+   t−

DRL   20-20

FR 1 DRL   20

FR 1 DRL   20   LIGHT

FR 1 DRL   20

FR 1 DRL   20

RELATIVE FREQUENCY (%)

IRT IN SECONDS

Figure 33. Relative frequency
distributions of IRTs for Animal
114 in the first session of response-
initiated DRL 20. The frequencies
are shown separately for IRTs following
reinforced (t+) and non-reinforced (t-)
responses. The conventional overall
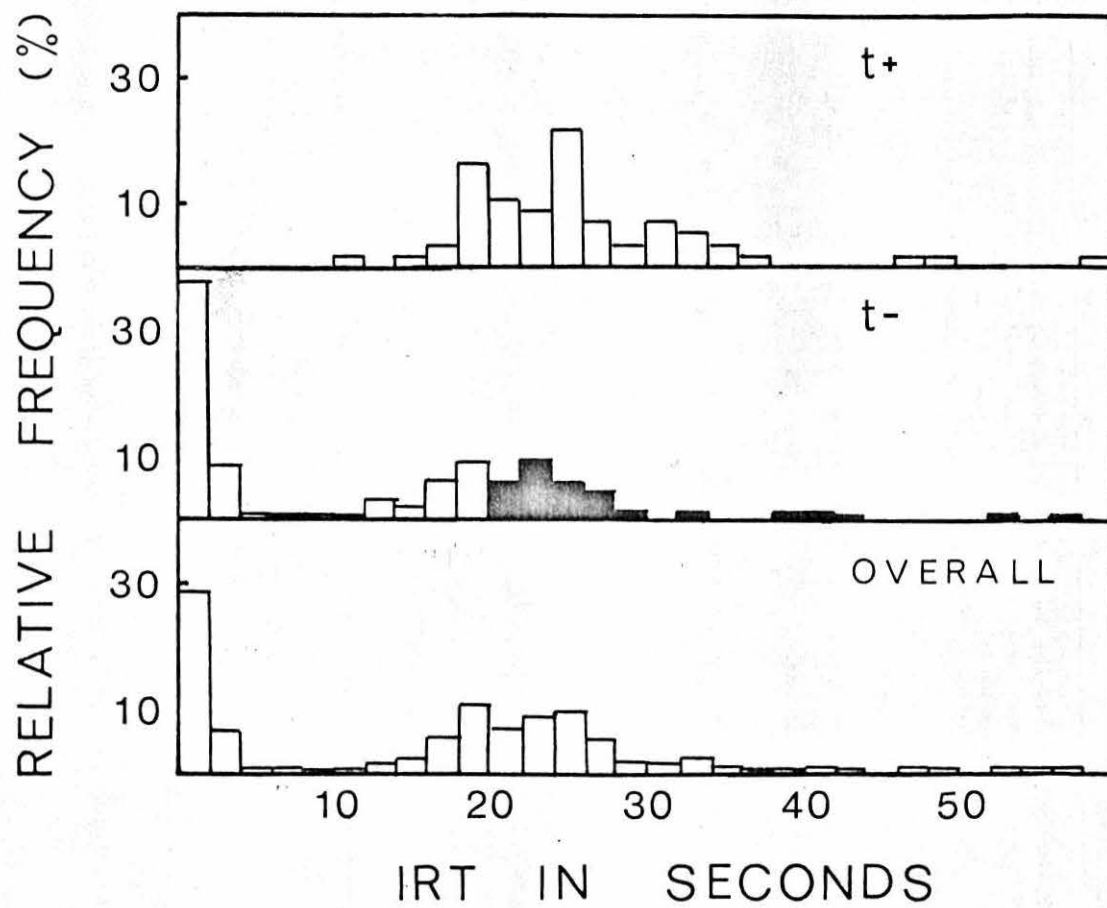frequency distribution is also shown
(overall).

Figure 34. The median and interquartile range of IRTs following reinforced responses for each subject in each of the five experimental conditions: (i) conventional DRL, (ii) response-initiated DRL (FR 1 DRL), (iii) FR 1 DRL with added stimulus (L), (iv) FR 1 DRL with the stimulus removed, (v) conventional DRL. Data are from the final two sessions on each condition.
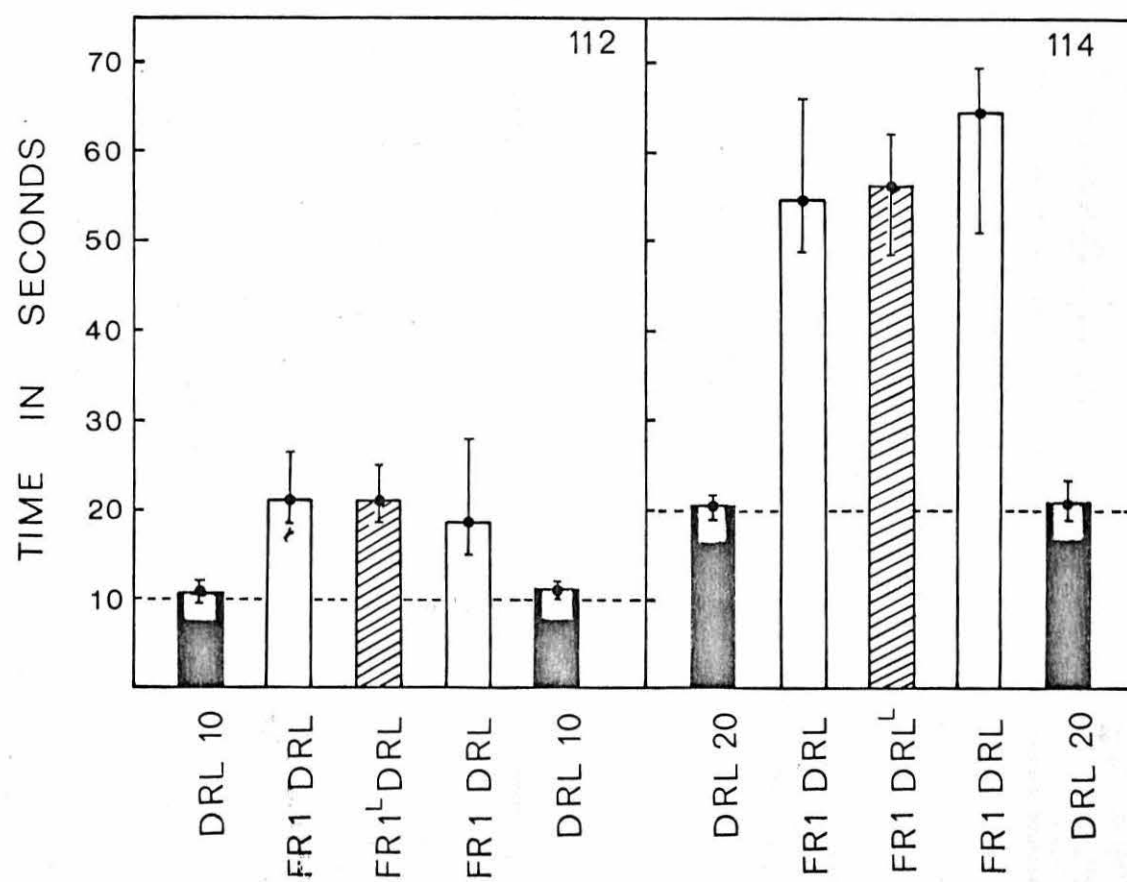
data were obtained from the final two sessions on each condition. The median IRTs following reinforcement on the response-initiated DRL 10-sec schedule were almost twice as long as those following reinforcement on the conventional DRL 10-10. The interquartile ranges were also greater on the tand FR 1 DRL 10 condition. The data from Animal 114 show that the median IRTs after reinforcement were more than twice as long as those occurring on DRL 20-20 and again the ranges were greater on the response-initiated conditions. The added stimulus appeared to have had no effect on either the median or the range of IRTs following reinforcement on the two tand FR 1 DRL schedules.

Figure 35 shows the conditional probability* of a burst following the first non-reinforced response after reinforcement on the final session of conventional DRL, on the first session of tand FR 1 DRL and on the final session of each of the remaining experimental conditions. The data from each subject show that the probability of a burst was approximately the same in the

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* calculated by dividing the number of times a burst followed first non-reinforced responses after reinforcement by the total number of such responses in a session.

Figure 35. For each subject the conditional
probability of a burst following the first
non-reinforced response after reinforcement
in (i) the final session of the conventional
DRL schedule, (ii) the first session of the
response-initiated DRL schedule [FR 1 DRL (1st)] ,
(iii) the final session of the response-
initiated DRL schedule (FR 1 DRL), (iv) the
final session of FR 1 DRL with the added
stimulus (L), (v) the final session of
FR 1 DRL with the stimulus removed, (vi)
the final session of the conventional DRL.
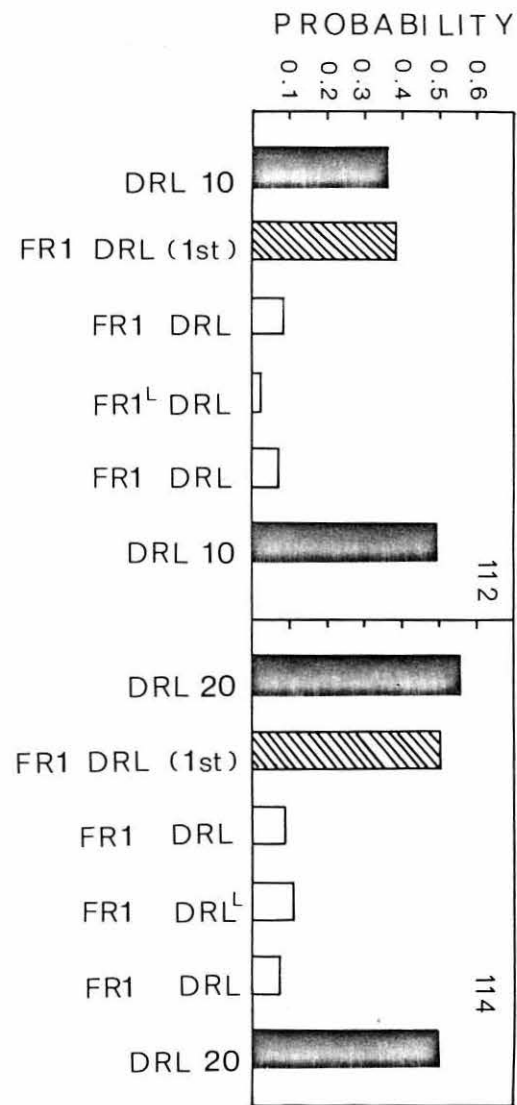
final session of conventional DRL and the first session
on the tand FR 1 DRL condition. There was, however,
a substantial reduction in burst probability on the
final sessions of each of the response-initiated
conditions. When the conventional DRL condition was
reinstated bursts increased markedly, returning to
their original level of occurrence.

Discussion

Studies which have used response-initiated FI
schedules (Neuringer and Chung, 1967; Shull, 1970 a)
have reported that substantial post-reinforcement
pauses occur on these schedules; the longer the
duration of the FI requirement the longer is the
post-reinforcement pause. In an investigation of
deprivation effects on DRL responding, Mechner and
Guevrekian (1962) employed a two-lever procedure
in which a response on one lever initiated the DRL
interval and a response on the second lever terminated
it. Using a DRL requirement of 5 sec, they reported
post-reinforcement pauses which were frequently much
longer than the DRL requirement. In the present
experiment, also, the post-reinforcement pauses which
developed were approximately twice as long as the DRL
value. The occurrence of pauses after reinforcement on
these response-initiated schedules reduces the density of

reinforcement. Such behaviour appears particularly
puzzling, especially in view of the commonly held
assumption that organisms adjust their behaviour so as
to maximise the frequency of reinforcement (cf. Logan
1960; Logan and Ferraro, 1970; Gott and Weiss, 1972).

In Chapter 2, it was suggested that the reinforcing
stimulus controls a pause on those schedules in which it
sets the occasion for a period of non-reinforcement, and
that on any given schedule the duration of the pause will
be directly related to the duration of the period of
non-reinforcement which the reinforcer signals. For
example, the post-reinforcement pause on FI is frequently
reported to be a constant proportion of the fixed interval
duration (Sherman, 1959; Schneider, 1969). The post-
reinforcement pause in response-initiated schedules may
be similarly accounted for. Taking as an example
performance on tand FR 1 DRL 10, reinforcement on this
schedule signals a minimum inter-reinforcement interval
of 10 sec. The subject may thus be expected to pause after
reinforcement for a proportion of the inter-reinforcement
time, say for two thirds of it, (i.e., 6.6 sec). In this
event, however, the reinforcer will now signal a longer
period of non-reinforcement, (i.e., 16.6 sec) which
should in turn lead to a longer post-reinforcement
pause (i.e., 11.0 sec). This produces a new inter-
reinforcement interval (i.e., 21.0 sec) and consequently

another new post-reinforcement pause and so on until
the proportions stabilise, when the mean duration of the
post-reinforcement pause is approximately 20 sec.

The pauses after reinforcement on the tand FR 1
DRL schedules and the increase in the duration of these
pauses as a function of the DRL requirement may thus
be understood in terms of temporal control by the
reinforcing stimulus. This may also account for the
performance of subjects on two-component DRL schedules
in which the value of t_2 is very short. It was found,
in Experiment 2, for example, that before subjects came
under the control of the 20-sec t_1 requirement on DRL
20-1 and DRL 20-3, there were pauses following reinforcement
longer than the DRL requirement; the duration of these
pauses increased when t_2 was increased from 1 sec to
3 sec. Responding on these schedules appears to resemble
performance on the response-initiated DRL schedules of
the present experiment.

The addition of a visual stimulus to either the
ratio or the DRL components of the tand FR 1 DRL schedules
did not facilitate the adoption of a reward maximisation
strategy by the subjects, enabling them to learn more
easily that a short IRT after reinforcement would put the

reinforced DRL component into effect. The apparent
ineffectiveness of the added stimulus in altering
the behaviour of the subjects of the present experiment
was similar to the ineffectiveness of the auditory
stimuli used in Experiment 3 with two-component DRL
schedules. It was thus seen, in both cases, that the
additional stimuli were redundant and this perhaps
indicates the strength of control by reinforced and non-
reinforced responses on these schedules.

According to frustrative non-reward theory the
probability of a burst occurring after a non-reinforced
response should be directly related to the degree of
expectancy of reinforcement for that response. When
reinforcement occurred on the conventional DRL schedule
used in this experiment it was fairly likely that the
next response would be reinforced; hence the expectancy
of reinforcement following these responses should have
been substantial. On the first session of reinforcement
omission, expectancy of reinforcement following a
reinforced response should still have been high. After
extended exposure to the omission condition, however,
and to a zero frequency of reinforcement following the

first response after reinforcement, expectancy should
have decreased markedly. It was found that after
stable performance had been established on the tand
FR 1 DRL schedule, there was a considerable decline
in the probability of a burst occurring following
the first non-reinforced response after reinforcement,
in comparison with the probability of a burst following
the first non-reinforced response on the conventional
DRL schedule, and on the first session of tand FR 1 DRL.
When, after the subjects had been exposed to the tand
FR 1 DRL schedules, the conventional DRL schedule was
reinstated, expectancy of reinforcement following
reinforced responses should have been restored. This
in turn appears to have brought about the recovery of
the original high frequency of response bursts.

GENERAL DISCUSSION

Azrin and Holz (1966) have stated that the
"effects of a behavioural consequence must be
analysed in terms of its discriminative properties
as well as its reinforcing or punishing properties (p.424)".
Evidence that the reinforcing stimulus in the basic

schedules of reinforcement does have discriminative
effects was presented in Chapter 2. The results presented
in this chapter also support this notion; they show that
the reinforcer which is presented as a consequence of
responses on DRL schedules also functions as an important
antecedent stimulus with temporal control of responding
which follows it.

According to Staddon (1972), the temporal control
of each response by the preceding response on the DRL
schedule can only be inferred from the regularity of
responding typically observed on this schedule. The
present experiments, however, have demonstrated that
such control does exist and that non-reinforced responses,
as stimuli, are significant determinants of performance on
DRL. These findings thus confirm the suggestion that
non-reinforced responses may function as discriminative
stimuli (Ferster and Skinner, 1957; Grice, 1965; Kelleher,
1966).

Apart from these antecedent stimulus effects,
however, in what other ways do reinforcement and non-
reinforcement of responses affect responding on DRL? In
the case of a conventional DRL 20-sec schedule, for example,

the 20-sec reinforcement contingency following reinforced responses appears to have the effect of decreasing rather than increasing the duration of IRTs after reinforcement. When the 20-sec reinforcement contingency is removed following a reinforced response, IRTs become much longer, due perhaps to the longer period of non-reinforcement signalled by the reinforcing stimulus (see Experiment 5).

The present experiments have indicated that an important factor in setting a lower limit to IRTs on DRL is the consequence of a response which fails to meet the IRT requirement. Apart from the fact that such responses are not reinforced, they also initiate a period during which reinforcement is not available. Performance on the two-component DRL schedules has shown that the longer the period of non-reinforcement (t_2) initiated by a non-reinforced response, the more likely is the subject to emit longer IRTs on the t_1 component. Though these findings apply to performance on the t_1 component it seems likely that the duration of the delay contingency following non-reinforced responses on t_2 has similar suppressive effects on responding in that component.

Several experimenters have suggested that response
bursts are not subject to schedule control and are a
source of unsystematic variability in responding (Blough,
1963; Meltzer, Maxey and Merkler, 1965; Meltzer and
Brahlek, 1967; Schneider and Neuringer, 1972). The
present experiments have provided considerable evidence
indicating that bursts are a function of the emotional
and frustrative effects arising from the omission of
expected reinforcement. This hypothesis successfully
accounts for the following findings: (i) bursts occurred
only following non-reinforced responses, on all the
schedules studied; (ii) bursts were more likely following
the first non-reinforced response after reinforcement than
following other non-reinforced responses (Experiment 1);
(iii) following t_1 responses, bursts became more frequent
as the duration of t_2 increased (Experiment 1); (iv) when
reinforcement was omitted (a) following responses which
met the DRL criterion in t_2, and (b) following the
first response after each reinforcement, the frequency
of bursts following these responses increased
substantially (Experiments 4 and 5); (v) after
extended exposure to reinforcement omission conditions,
the frequency of bursts decreased relative to performance
on the first session of reinforcement omission. Though
there is no apparent reinforcing contingency maintaining

bursts on DRL, these results clearly indicate that bursts, when analysed in relation to each component (t_1 and t_2) of the schedule, are systematically related to the schedule parameters and particularly to antecedent stimulus events.

A notable feature of performance on many of the schedules studied was the failure of the subjects to maximise reinforcement. On those schedules in which the duration of t_2 was shorter than t_1, as well as on the response-initiated schedules, the animals paused after reinforcement for a relatively long period of time. This occurred despite the fact that these post-reinforcement pauses resulted in a reduction in the frequency of reinforcement.

It has been argued in the present thesis that this phenomenon is due to the inhibitory or suppressive effects of the reinforcer; when the reinforcer sets the occasion for a period of non-reinforcement, on any schedule, a post-reinforcement pause occurs, the duration of which is related to the period of non-reinforcement signalled by the reinforcer. The evidence for such effects on other schedules of reinforcement, e.g., on

the FI schedule (Sherman, 1959; Harzem, 1968; Schneider, 1969), on VI (Lachter, 1970; Martin, 1971), on FR (Berryman and Nevin, 1962; Neuringer and Schneider, 1968) and on VR (Farmer and Schoenfeld, 1967) has been discussed in Chapter 2. Longer durations of the post-reinforcement pause do not usually reduce the frequency of reinforcement on either the FI or the VI schedules. On the ratio schedules, however, pausing after reinforcement delays the arrival of the next reinforcer and serves to reduce the rate of reinforcement.

Evidence has been presented which is consistent with the notion that non-reinforced responses also acquire inhibitory properties on DRL. However, on those schedules in which the IRT requirements on both components were of equal duration, IRTs were found to be longer following reinforced responses than following non-reinforced responses. Bursts following non-reinforced responses accounted for some of the shorter IRTs. However, on DRL schedules, even when bursts are not taken into account, the IRTs following non-reinforced responses are shorter than those following reinforcement (Carter and Bruno, 1968 a; MacDougall et al., 1969; Weiss, 1970). As it has been suggested that bursts are

due to the frustrative effects of non-reinforcement,
it is possible that the shorter IRTs following non-
reinforced responses, in other class intervals than
the 0-2 sec category, are also due to similar
frustration effects.

On the other hand, a response accompanied by the
reinforcing stimulus may be a more intense source
of stimulation for the subject than a non-reinforced
response. Just as in classical conditioning there is
a direct relationship between the intensity of the
CS and the magnitude of the CR (Razran, 1949; Kamin,
1965), so also in operant conditioning the inhibitory
properties of stimuli may be a function of their
intensity. If longer IRTs following reinforcement
are a function of the intensity of stimulation provided
by the reinforcer, then increasing the intensity, for
example, by increasing the magnitude or concentration of
the reinforcer, should lead to still longer IRTs after
reinforcement. This possibility was investigated in
the experiments to be described in Chapter 8. As an
introduction to these experiments, a selective review
of the literature on magnitude of reinforcement is
presented in the following chapter.

CHAPTER 7

THE EFFECTS OF REINFORCEMENT MAGNITUDE ON

FREE OPERANT RESPONDING: A SELECTIVE REVIEW

In the investigation of "magnitude of reinforcement" a number of techniques have been used to manipulate the reinforcer. The different ways in which reinforcers may be presented have been described by Guttman (1953) as follows: (i) simple food particles of various weights or sizes, (ii) various numbers of food particles of equal size and weight, (iii) exposure to food for various lengths of time, (iv) different concentrations of a soluble nutrient. The following review deals with

studies which have used one or more of these methods
to investigate reinforcement magnitude effects on
responding on the basic schedules of reinforcement.

A fundamental argument of the present thesis is
that the reinforcer acts not only as a consequence of
behaviour, increasing response rate, but also has
antecedent stimulus properties, e.g., discriminative
or inhibitory properties, which affect responding for
a period of time following the occurrence of the
reinforcer. This distinction has not, for the most
part, been recognised in previous reinforcement
magnitude studies. Where the data permit, however,
the experiments reviewed in this chapter will be
considered with reference both to the antecedent and
to the consequent effects of the reinforcer.

CONTINUOUS REINFORCEMENT

The effects of reinforcement magnitude on the
acquisition of a lever-pressing response, on a CRF
schedule, was studied by Guttman (1953). Using as
reinforcement four sucrose concentrations, 4%, 8%, 16%
and 32%, he found that the average time taken by rats
to make 250 responses on CRF decreased progressively as
concentration increased. Response rate early in

acquisition increased as a function of magnitude, but this relationship became nonmonotonic after 100 reinforcements - response rate during the final stages of acquisition was lower for those animals with the 32% reinforcer than for those with either the 16% or the 8% concentration.

Guttman's results were confirmed by Hurwitz, Walker, Salmon and Packham (1965), who found that early in acquisition response rate was higher when a 32% rather than an 8% sucrose solution was used as the reinforcer; after several reinforcements on CRF this relationship was reversed. Nonmonotonic rate-concentration functions, similar to those reported by Guttman for rats, have also been found for monkeys maintained on CRF (Schrier, 1965).

Different volumes of water were used as reinforcers in a study by Van Hartesveldt (1973), who found that acquisition was fastest for rats which received larger reinforcements. When responding was established on the CRF schedule, the volume of the reinforcer was reduced; this resulted in an increase in response rate. A similar inverse relationship between rats' response rate and the volume of a sucrose reinforcer has been reported by Fowler and Notterman (1974).

It has been suggested that the lower response
rates on high concentrations might be due to the
interference with the operant response caused by
increased consummatory behaviour following reinforcement
(Guttman, 1953). Fowler and Notterman (1974), on the
other hand, have argued that a satiation factor may
be involved.

FIXED-INTERVAL

Guttman (1953) carried out the first parametric
investigation into the effects of reinforcement
magnitude on FI schedules. Using different concentrations
of sucrose solution as reinforcers, 4%, 8%, 16%, and 32%,
and rats as subjects, he employed both within-subjects
and between-subjects designs. He concluded that rate of
responding on FI was an approximately logarithmic
function of concentration. A similar effect on responding
was found for reinforcement amount by Hutt (1954), who
used a variety of liquid reinforcers.

A series of experiments, again with rats as subjects,
by Collier and Siskel (1959), Collier and Myers (1961),
Collier and Willis (1961), in general lend support to
Guttman's findings but also contain some differences.
The Collier studies found that response rate was an
increasing function of sucrose concentration and volume,

but only within a given range. At higher levels of concentration and volume the function became nonmonotonic and a downturn in response rate occurred. Similar findings for saccharin reinforcement were also reported (Collier, 1962).

To account for the drop in response rate on the higher concentrations and volumes, Collier and Myers (1961) suggested that responding may be suppressed by "momentary satiation" which is a result of increased reinforcement. A study by Walker (1969) casts some doubt upon the satiation notion and also reports effects of magnitude of reinforcement which run counter to the findings of earlier studies. Different baseline sucrose concentrations, 8% and 32%, were assigned as reinforcers to two groups of rats on an FI 1-min schedule. During test sessions, four new concentrations - 4%, 16%, 64% and either 8% or 32% - were presented for four sessions each; the two groups of subjects were returned to the baseline reinforcement between tests. Though response rate was higher for the 32% group than for the 8% group, during tests with the four different concentrations response rate did not change systematically as a function of the concentration of the reinforcer. However, it was observed that the highest concentration gave rise to low response rates.

This depression in responding supports the finding
of the Collier studies that rate of responding is
reduced on high reinforcer concentrations. But Walker
also recorded the number of times the animals made
approaches to the reinforcement tray and he found no
evidence of a decline in such behaviour on the high
concentrations. He concluded that "...there was no
general cessation of behaviour which might merit the
term satiation (p.173)".

Details of effects on response patterning within
the intervals were not recorded in any of the above
mentioned studies. However, Stebbins, Mead and Martin
(1959), using different sucrose concentrations, measured the
proportion of responses that were made by rats in each
successive fifth of the interval between reinforcements,
on an FI 2-min schedule. Four concentrations of sucrose
were used: 5%, 12.7%, 32% and 50%. Overall response
rate was a direct function of concentration, but the
distribution of responses within the intervals varied
with reinforcer magnitude. A smaller proportion of
responses occurred early in the interval on 5% than on
the 32% concentration. It was also the case that fewer
responses occurred early in the interval on the 50%
concentration than on 32%. Stebbins et al. suggest that
temporal discrimination may be better on the higher

concentrations, producing the more pronounced scalloping.
This is consistent with the notion put forward by
Walker (1969) - to account for low response rates on high
reinforcement magnitudes - that large rewards produce a
more precise temporal patterning of responding.

All the studies mentioned so far have employed
liquid reinforcement. However, in two experiments by
Meltzer and Brahlek (1968; 1970) solid food was used
and some of the liquid reinforcement findings appear to
have been confirmed. Meltzer and Brahlek (1968) used two
groups of rats. One group was given one food pellet
as the reinforcer, the other group was given three pellets.
They found that overall response rates were highest
in the three-pellet condition. But they also reported
that the percentage of responses in each quarter of the
intervals between reinforcements were the same for both
conditions. The study conducted by Meltzer and Brahlek
(1970) was a within-subject replication of their earlier
experiment and produced similar results.

Keesey and Kling (1961), on the other hand, using
pigeons as subjects and different amounts of food as
reinforcers, have reported experiments which have yielded
no systematic effects of magnitude of reinforcement on FI

response rate. This result resembles that of Walker
(1969), who used a liquid reinforcer, with rats as
subjects, and found no systematic relationship between
reinforcement magnitude and responding on an FI schedule.

Of the studies considered so far some have reported
that response rate increases directly as a function of
reinforcement magnitude, some that response rate decreases
on higher reinforcement magnitudes and some have reported
no effect on responding of changes in the reinforcer.
This is further complicated when the effects of prior
exposure to different amounts of reinforcement are
considered. Collier and Marx (1959), for example,
found that the reward magnitude received by rats during
magazine training affected subsequent performance on
an FI schedule. Responding on FI with an intermediate
concentration of a sucrose reinforcer was highest for
those subjects which were magazine trained with a low
concentration; response rate was lowest for subjects
magazine trained with the higher concentration. Similar
results were reported by Pieper and Marx (1963).

Though these studies suggest that response rate
for a given reinforcement magnitude is inversely related
to the magnitude of the reinforcer previously experienced,

Walker (1969) has reported a direct relation between response rate on FI and magnitude of reinforcement previously experienced on the same schedule.

The situation therefore is one which might suggest that "amount of reinforcer frequently is quite an ineffective variable when manipulated in laboratory studies, and that there is considerable discrepancy between the results of studies which appear to be equally well designed and executed" (Kling and Schrier, 1971, p.630). These apparent inconsistencies in the literature probably arise from a confusion of the two main functions that a reinforcing stimulus may have. In Chapter 2 evidence was considered, suggesting that the reinforcer on FI schedules, apart from having rate-enhancing or "motivational" effects, may also depress responding immediately after it occurs. Some recent studies concerned with magnitude of reinforcement effects add further weight to this argument.

Staddon (1970 a) analysed the effects of the preceding reinforcement magnitude on response patterning in the following fixed interval. He manipulated the duration of reinforcement with pigeons on an FI 1-min schedule. Five different durations of access to grain

occurred randomly within test sessions; these durations
ranged from 1.3 to 9 sec. Post-reinforcement pauses
varied directly and running rate inversely as a function
of the reinforcement duration. initiating each fixed.
interval. Overall response rate was thus an inverse
function of preceding reinforcement magnitude. These
findings were interpreted by Staddon (1970 a) as
indicating that the reinforcer has temporal inhibitory
effects on FI schedules; when the duration of the
reinforcer is increased these inhibitory after-effects
are enhanced.

A study by Jensen and Fallon (1973) also provides
evidence regarding the after-effects of reinforcement
magnitude. Rats responded on a multiple FI FI schedule,
each complete cycle of which was separated by a variable
time out period (mean = 60 sec). Reinforcement
consisted of access to water and the duration of this was
kept constant at the end of the second component, but
was systematically varied in the first component. A
differential stimulus accompanied each component. Each
of the four rats used was run until stable on each of
three reinforcement durations. It was found that: (a)
response rate in the first component increased as a
function of the reinforcement magnitude which occurred
at the end of that component; (b) there was no systematic
change in response rate in the second component as a
function of reinforcement magnitude in the first; (c)
there was no systematic change in index of curvature in
either component.

A number of 10-session blocks were interspersed among the baseline conditions of this experiment to assess the effects of reinforcement omission. A different reinforcement magnitude was used in the first component during each of these 10-session blocks; reinforcements on the first component were omitted on 50% of the cycles of the multiple FI schedule. During these reinforcement omission phases it was found that: (a) there was no systematic change in response rate or index of curvature in the first component as a function of reinforcement magnitude in that component - response rate was uniformly lower than in the baseline (100% reinforcement) conditions; (b) response rate in the second component, after reinforcement, was an inverse function of reinforcement magnitude - response rate was again uniformly lower than in baseline conditions; (c) index of curvature increased following reinforcement as magnitude of reinforcement increased; (d) response rate tended to be higher than in baseline conditions following the omission of reinforcement.

We find then that, in the baseline conditions of this experiment, reinforcement magnitude, when presented at the end of an FI component, had the effect of increasing the response rate which preceded the reinforcement, but also had the effect, in the omission sessions, of

decreasing the response rate which followed reinforcement. The decrease observed in response rate as a function of the preceding reinforcement magnitude, is consistent with Staddon's (1970 a) findings. The experiment also suggests that the suppressive effect of reinforcement is most pronounced in contrasted reinforcement conditions, as prevailed, for example, during the omission phases.

Another recent study (Meltzer and Howerton, 1973) has shown that the number of pellets delivered at reinforcement can increase response rate in the interval that it terminates as well as depress responding in the subsequent interval. Rats responded on an FI 3-min schedule in which intervals, terminated by 1 or 3 food pellets, preceded intervals in which the reinforcer was 2 food pellets. A discriminative stimulus was present throughout each interval, signalling the delivery of 1, 2 or 3 pellets upon completion of the interval. It was found that response rate was higher in intervals which were terminated by 3 food pellets than it was in intervals terminated by 1 pellet. However, response rate in those intervals terminated by 2 food pellets but preceded by a 3-food pellet reinforcer was lower than in intervals initiated by 1 food pellet.

The findings derived from these studies (Staddon,
1970 a; Jensen and Fallon, 1973; Meltzer and Howerton,
1973) are compatible with the suggestion that the lower
response rate following greater magnitude of
reinforcement is a function of enhanced inhibitory
effects of the reinforcer. These results, however,
particularly the increase in the index of curvature as
a function of reinforcement magnitude (Jensen and Fallon,
1973), are also consistent with the notion put forward
by Stebbins et al. (1959) and Walker (1969) that lower
response rates are a function of more precise temporal
patterning following larger reinforcements. These
results are also in accord with the suggestion that to
increase the magnitude of reinforcement is to enhance
its discriminative effect, producing a consequent
improvement in general precision of performance (Di
Lollo, Ensminger, and Notterman, 1965; Notterman and
Mintz, 1965). An attempt is made in Chapter 8 to
determine whether lower response rates on the FI schedule
reflect increased inhibitory after-effects of larger
reinforcement magnitude or an enhanced precision of
performance.

FIXED-RATIO

Hurwitz et al. (1965) used two different concentrations
of sucrose, 8% and 32%, as reinforcers in an FR 20 schedule.
A different group of rats was assigned to each concentration.

Though response rate was higher on the 32%
concentration during the early sessions, after 18
sessions on FR 20, response rate was higher for the
group maintained on 8% sucrose than for the group
maintained on 32%. When the groups were further
subdivided, so that two groups experienced shifts
in concentration and two were maintained on constant
concentrations, Hurwitz et al. report that, though
the effects of reinforcement shifts were not
statistically significant, the response rate of those
subjects shifted from 8% to 32% concentration appeared
to fall more than the rate for subjects which remained
on 8% concentration, while the rate for subjects kept
on 32% concentration appeared to fall more than the
rate for subjects changed from 32% to 8% concentration.

In a study by Weinstock, White and Bolles (1965),
rats responded on an FR 10 schedule for different
concentrations of saccharin. Weinstock et al. found that
the response rate concentration curves were, on the
lower concentrations, an increasing, and then, on the
higher concentrations, a decreasing function of the
concentration of the saccharin reinforcer.

Powell (1969) used two durations of grain
presentation - 2.5 sec and 4 sec - as reinforcement.
Pigeons responded on different FR values, and

reinforcement duration was   (a) alternated between
sessions, and (b) changed within sessions. Each
magnitude condition occurred in the presence of a
differential stimulus. Powell found that post-
reinforcement pause duration was an inverse function
of the duration of the reinforcer. Only one of the
four pigeons used showed a consistently higher running
rate as a function of access to food, while the others
showed no systematic change in running rate. Overall
response rate, though not presented by Powell, would
presumably show an increase as a function of reinforcer
duration.

The effects of reinforcement duration on discrete-
trials FR responding, where each reinforcement was
followed by a 10-sec TO, has been investigated by
Bitgood and Platt (1973). Two pigeons were used as
subjects. As reinforcers there were three different
durations of access to grain - 2, 4 and 8 sec - each
presented in the presence of a differential stimulus
on every third test session. Start speeds and running
rates were an increasing function of reinforcement
duration when the schedule was discrete-trials FR 60,
but not when it was discrete-trials FR 30. When both
pigeons were placed on a conventional FR 60 schedule it

was found that the increasing relation between running
rate and reinforcement duration was obtained for only
one subject. Though the authors do not report it,
inspection of the data shows a tendency for the
duration of the post-reinforcement pause to increase as
a function of reinforcement duration.

The inverse relation between response rate and
sucrose concentration (Hurwitz et al., 1965), and between
response rate and higher concentrations of saccharin
(Weinstock et al., 1965), is in apparent contradiction
with Powell's (1969) finding of a direct relation
between response rate and reinforcement magnitude.
However, there were considerable differences among
these experiments, one of these being the differential
stimuli in the Powell study, which were not present in
the other two experiments. It has been shown that when
a differential stimulus, signalling the magnitude of the
up-coming reinforcement, is presented on an FI schedule
it has a rate-enhancing effect on performance (Meltzer
and Howerton, 1973).

Comparison of these studies with the Bitgood and
Platt (1973) findings with discrete-trials FR schedules,
is difficult, as the TO contingency in the latter probably

reduced the likelihood that after-effects of reinforcement
magnitude would be shown. Bitgood and Platt's post-
reinforcement pause findings from the conventional FR
60 schedule, on the other hand, are not in agreement
with those of Powell (1969). This adds weight to
the suggestion that the addition of stimuli in Powell's
experiment was a factor which helped to increase
responding.

Progressive-ratio schedules have been used in
some studies on the effects of reinforcement magnitude.
In this schedule the ratio requirement increases
following each successive reinforcement; at some FR
value (the "breaking point") the subject ceases to
respond. It has been reported that the ratio size
at which responding ceases on progressive ratio
schedules is an increasing function of both the
concentration and volume of a sweetened milk reinforcer
(Hodos, 1961; Hodos and Kalman, 1963). This
relationship appears consistent with the finding that
following exposure to a CRF schedule (Guttman, 1953),
or an FI schedule (Hutt, 1954; Collier and Willis,
1961), animals' resistance to extinction is an
increasing function of the reinforcement magnitude used
in the schedule.

VARIABLE-INTERVAL

Guttman (1954) varied concentrations of sucrose and glucose solutions on a VI 60-sec schedule. He used rats in a within-subject design and presented a different concentration on each session. Testing on different reinforcement magnitudes was carried out as soon as the animals were placed on the VI schedule. Rate of bar-pressing was found to be an increasing function of concentration of sucrose and of glucose. Similar results have been obtained for rhesus monkeys by Conrad and Sidman (1956) and Schrier (1965), following procedures very similar to Guttman's. They also found that at high levels of concentration the functional relationship between response rate and magnitude became nonmonotonic.

Jenkins and Clayton (1949) found that the response rate of pigeons on VI schedules was higher when the duration of access to grain, used as the reinforcer, was 5 sec than when it was 2 sec. Catania (1963) also using duration of access to grain, and Keesey and Kling (1961) using amount of solid food, report experiments with pigeons in which they adopted procedures similar to those employed in the Jenkins and Clayton study, i.e., the subjects had several sessions on each magnitude. They found no systematic relationship between response rate and reinforcement magnitude.

Keesey and Kling (1961) also used a procedure
in which the amount of reinforcement and the stimulus
conditions associated with different amounts were
varied within experimental sessions. With this
procedure they found that response rate varied as a
function of reinforcement amount - the effect being
particularly pronounced after stimulus change and early
in the changed magnitude condition.

A recent study (Campbell and Seiden, 1974)
investigated the effects of different volumes of a
water reinforcer on rats' responding on a VI 20
extinction schedule. The schedule consisted of
3-min periods during which the VI was in effect in the
presence of a one stimulus, alternating with 3-min
periods of extinction in the presence of a different
stimulus. In one experiment the subjects were trained
on a single volume of 0.04 ml, and then were tested on
different volumes of the reinforcer, i.e., 0.01, 0.02,
0.06, 0.08 and 0.10 ml; a given volume was presented
for one experimental session. In the second experiment
three groups of rats were trained with 0.01, 0.04 and
0.10 ml reinforcers; each group was run exclusively on
its designated water volume.

Campbell and Seiden (1974) report that response rate was an increasing function of reinforcement magnitude only in the first experiment. The duration of the post-reinforcement pause was directly related to amount of reinforcement in both experiments. These data suggest that the experimental design used to test the effects of magnitude of reinforcement may be important in determining the results obtained. Effects may be different when obtained in conditions which allow different magnitudes to be presented to the same subject in close temporal proximity, e.g., within sessions or on successive sessions, and when no such temporal contrast occurs, e.g., in studies using a between-subjects design.

The effects of reinforcement magnitude on post-reinforcement pause duration is consistent with the notion put forward in Chapter 2, that the reinforcer may have inhibitory effects on VI schedules. However, as was the case with performance on FI schedules the longer pausing may reflect an increase in the temporal precision of performance (Stebbins et al., 1959; Notterman and Mintz, 1965; Walker, 1969).

DIFFERENTIAL REINFORCEMENT OF LOW RATE

Little research has been conducted on the effect of magnitude of reinforcement on responding on DRL schedules. One study by Beer and Trumble (1965),

employed a two-lever procedure, similar to that used
by Mechner and Guevrekian (1962);   only IRTs
exceeding 18 sec, which occurred between a response
on the first lever and a response on the second lever,
were reinforced. The subjects were rats. 1, 2, and
4 food pellets were used as reinforcers, each quantity
being presented in five-minute blocks within sessions
and each having a differential stimulus, associated
with it. (It is not clear from details given of
the procedure whether testing with different magnitudes
was carried out during acquisition or after stable
responding on the schedule had been established).
With regard to responses on the first lever which were
followed by responses on the second lever, it was
reported that both the duration of IRTs and efficiency
declined with increased number of pellets.

The Beer and Trumble experiment confirms the
results of other experiments on FI, VI and FR which
have found an enhancement of response rate in the
presence of stimuli associated with increased
reinforcement magnitude. As their study did not provide
data concerned with post-reinforcement pause durations
or with any response sequences other than IRTs occurring
between responses on the first and second levers, it is

not possible on this account,to make an assessment
of the after-effects of reinforcement magnitude
upon responding on two-lever response-initiated DRL
schedules.

RESPONSE FORCE

Di Lollo et al. (1965) trained 5 groups of rats
to press an isometric lever. The rats were reinforced
with either 1, 2, 3, 4 or 5 pellets on responses
meeting or exceeding an 8-gm force criterion. After
10 acquisition sessions all the subjects were shifted
to 3 pellets. The mean and range of the force of bar-
pressing varied inversely with amount of reward by the
end of acquisition; on the smaller reinforcement
magnitudes response force was frequently far in excess
of the 8-gm criterion. When the shift to 3 pellets
occurred, bar-presses in the 1 and 2 pellet groups
were reduced in force and variability. The 4 and 5
pellet groups' responses increased in force and
variability, though the latter effect was temporary.
Similar results have been reported by Fowler and
Notterman (1974).

Di Lollo et al. (1965) and Notterman and Mintz
(1965) have explained their results in terms of a
discriminative effect of the reinforcer, which is
enhanced when the magnitude of reinforcement is increased.

They have argued that the major effect of magnitude of reinforcement is to determine the precision of performance.

CONCURRENT SCHEDULES

There are constraints upon behaviour in single-operandum schedules of reinforcement: only one response class produces reinforcement and there is normally only a single reinforcement magnitude available at any one time. Concurrent schedules provide a situation where the animal can choose between responses and between reinforcers or reinforcement frequency. Many investigators have found concurrent schedule performance sensitive to the magnitude of reinforcement variable.

Catania (1963), having found that different durations of grain reinforcement on a standard VI schedule produced little change in pigeons' overall response rate, placed them on concurrent VI schedules and varied the reinforcement durations on two keys. He found that rate of pecking on a key was directly proportional to the duration of reinforcement on that key. Brownstein (1971), using a concurrent procedure with response-independent reinforcement,

found that the length of time that a pigeon chose,
by pecking a key, to remain in each of two schedules
was a direct function of reinforcement duration in
that schedule.

On the basis of such experiments Catania (1966)
and Brownstein (1971) have suggested that there is a
matching relationship between response rate and
reinforcement duration on concurrent schedules,
expressed as follows:

(a)
$$\frac{r_1}{r_1 + r_2} = \frac{d_1}{d_1 + d_2}$$

where r and d represent number of responses and
reinforcement magnitude respectively, subscripts
representing the schedules .

This is analogous to the relationship which
exists between frequency of reinforcement and response
rate (Herrnstein, 1961, 1970), i.e.:

(b)
$$\frac{r_1}{r_1 + r_2} = \frac{f_1}{f_1 + f_2}$$

where f represents the number of reinforcements
provided by a given schedule.

Moreover, Premack (1965) has suggested that,
"If, in fact, rate and duration (of reinforcement)
prove to yield comparable functions, it would be
additionally desirable to reduce both cases to the
same variable ... _i.e._ the rate by duration product
(p.153)" :

$$\text{(c)} \qquad \frac{r_1}{r_1 + r_2} = \frac{f_1 d_1}{f_1 d_1 + f_2 d_2}$$

where fd is the product of frequency and magnitude
of reinforcement in a schedule.

An experiment by Neuringer (1967) lends support
to Premack's suggestion. Using pigeons on a
concurrent chain procedure in which reinforcement rate
was held constant, he found that relative choices in
the initial links approximately matched relative total
access to reinforcement in the terminal links. Rachlin
and Baum (1969), also with pigeons, but using a

signalled reinforcement procedure, found that response
rate in the standard component of a pair of concurrent
VI schedules was inversely related to reinforcement
duration in the signalled component. Further evidence
for the notion of the functional equivalence of
reinforcement frequency and reinforcement duration comes
from a study by Ten Eyck (1970), who varied both
reinforcement duration and reinforcement frequency
for pigeons on concurrent chain schedules. The
relative rate of responding on the initial links
approximately matched relative total access to
reinforcement.

However, conflicting evidence comes from studies
by Fantino, Squires, Delbruck and Peterson (1972), and
Todorov (1973), who found that rate of reinforcement
had a more potent effect upon pigeons' choices than
did magnitude of reinforcement: rate of reinforcement
affected choice in a directly proportional manner,
whereas reinforcement duration did not. There are
considerable procedural differences between these
studies of Fantino et al. (1972) and Todorov (1973),
both of whom used concurrent VI VI schedules, and those
of Neuringer (1967), Ten Eyck (1970) and Rachlin and
Baum (1969). The latter experiment employed signalled
reinforcement, while in the other two studies by
Neuringer and Ten Eyck, concurrent chain schedules were
used.

Walker, Schnelle and Hurwitz (1970) who manipulated
reinforcer duration, with rats as subjects, also failed
to find matching of relative response rate and
relative reinforcer duration. However, in accord with
Rachlin and Baum (1969), it was found that the rate of
response on the manipulandum that produced reinforcers
of constant duration varied inversely with the duration
of reinforcers delivered by an alternative manipulandum.
Walker et al. observed that the sum of the response rates
on both manipulanda was inversely related to the sum
of the reinforcer durations and they postulated a
general rate-suppressing effect of increasing reinforcer
amount. Collier, Vogel and Rega (1966), also using rats,
varied concentrations of sucrose reinforcer on concurrent
CRF schedules and found that preference, in terms of
choice, was for the highest concentration. Concurrent
FR schedules were used by Collier and Rega (1971);
with rats as subjects, they found that the percentage
of bar-pressing on the higher sucrose concentration
proved to be a linear function of the log of the ratio
of concentrations.

The data from concurrent schedules suggest that
when more than one magnitude is available to an animal
then the magnitude variable is an effective determinant

of choice behaviour. Animals prefer greater magnitudes

of reinforcement.

In some experiments, choice of different magnitudes

has been presented on a single manipulandum. Shimp

(1968) varied the duration and frequency of reinforcement

for two classes of inter-response times — 1.5 to 2.5

sec and 3.5 to 4.5 sec —   on a single response-

key. Visual discriminative stimuli accompanied the two

time intervals in which reinforcements were arranged

by a 1-min variable-interval schedule. Pigeons

were the subjects in this experiment. The relative

frequencies of these inter-response times were found

to be orderly functions of both reinforcement variables.

There was not, however, a matching relationship between

reinforcement and responding. Moffitt and Shimp (1971)

employed a similar procedure as Shimp (1968) but used

two keys; one range of inter-response times was

reinforced on each key. Their results replicated the

earlier one-key findings.

Hendry (1962) and Hendry and Van-Toller (1964)

also demonstrated the effectiveness of the magnitude

of reinforcement variable in single manipulandum
schedules. Hendry (1962) presented different groups
of rats with 1 to 10 food pellets according to the
length of their terminal IRT on an FI schedule of
reinforcement. In one group, the animals' rate of
bar-pressing decreased over the entire fixed interval
when a larger reinforcement was made contingent on a
longer terminal IRT. The opposite results were obtained
in the other group for which a shorter terminal IRT
earned more food. Hendry and Van-Toller (1964) showed
similar, though more limited effects of correlated
reinforcement magnitude on FR responding.

Comparison of concurrent schedules with single
schedule studies is made difficult by the response
measures typically employed in the concurrent schedule
studies, such as overall response rate (responses on a
given schedule divided by total session time). As Catania
and Reynolds (1968) have pointed out, "the power of positive
reinforcement lies in its capacity to control not only
the occurrence of responses but also their temporal
relationship to other responses and to events such as
reinforcement". A more detailed analysis of performance
might help to establish the nature of such temporal
relationships on concurrent schedules and how they are
affected by changes in the magnitude of reinforcement.

CHAPTER 8

THE EFFECTS OF REINFORCEMENT MAGNITUDE

ON SCHEDULE PERFORMANCE

Early investigations into the relationship between
the magnitude of reinforcement and the speed of response
suggested that increasing the former would result in an
increase in the latter. This phenomenon was reported
both with free-operant responding (Guttman, 1953) and
with runway performance (Crespi, 1942; Zeaman, 1949).
The findings seemed to be straightforward and consistent
with common-sense notions of the effects of reward. The
rapid shifts in performance, produced by changing the

magnitude, were attributed by most theorists to concomitant changes in motivation (cf. Bartoshuk, 1971). Subsequent research has shown, however, that the relationships involved are more complex than previously thought, and several reviews of the literature have indicated that at present the evidence is inconclusive (Neuringer, 1967; Kling and Schrier, 1971; Bolles and Moot, 1972 - see Chapter 7).

For example, Guttman (1953) found that on an FI schedule the overall response rate was a direct function of the concentration of the sucrose solution used as reinforcer, but while this has been confirmed by several studies which employed different types of reinforcement (e.g., Hutt, 1954; Stebbins et al., 1959; Meltzer and Brahlek, 1968; 1970), other experimenters have reported that, at higher sucrose concentrations, response rate is inversely related to concentration (e.g., Collier and Siskel, 1959; Collier and Myers, 1961; Collier and Willis, 1961). Moreover, in some experiments, changing the magnitude of reinforcement has been found to have no systematic effect on responding on an FI schedule (Keesey and Kling, 1961; Walker, 1969).

In the case of the FR schedule, Powell (1969) found a direct relationship between the amount of reinforcer and response rate, whereas Hurwitz et al. (1965) found this

relationship to be inverse when the concentration of
sucrose solution was manipulated. Weinstock et al.
(1965) found that on low concentrations of a saccharin
reinforcer there was a direct relation between response
rate and concentration ; on higher concentrations this
relationship was reversed.

This apparent inconsistency in the literature
probably arises from a confusion of the two main functions
that a reinforcing stimulus may have. It has been argued
in this thesis that the reinforcer, as well as "motivating"
responding, may have inhibitory after-effects on schedules
of reinforcement. Either, or both of these, the antecedent
and the consequent effects of the reinforcer, may be
altered when the magnitude of the reinforcer is changed,
with what appear to be contradictory results.

Evidence in support of the inhibition hypothesis
comes from studies which have reported antecedent effects
of increases in the magnitude of the reinforcer, resulting
in longer post-reinforcement pauses (Staddon, 1970 a) or
a lower rate of responding (Jensen and Fallon, 1973;
Meltzer and Howerton, 1973) on FI schedules and longer
post-reinforcement pauses on a VI schedule (Campbell and
Seiden, 1974).

However, an alternative explanation of these
results is that increasing the magnitude of reinforcement
enhances its discriminative effect, so that the
performance improves in precision (Stebbins et al., 1959
Di Lollo, et al., 1965; Notterman and Mintz, 1965;
Walker, 1969). This view would seem to be supported by
the occurrence, in FI schedules, of longer post-reinforcement
pauses when reinforcement magnitude is increased, since
this results in fewer responses with little or no
reduction in the frequency of reinforcement. The question
remains unresolved, however, whether in those schedules .
where the frequency of reinforcement decreases as a
result of longer pauses, the effect of increasing the
magnitude is to shorten the post-reinforcement pause,
or to increase response rate, or both.

The present chapter is mainly concerned with this
problem, as well as with describing in detail the extent
to which stimulus properties of the reinforcer, on
different schedules, are altered by changes in the magnitude
of the reinforcer. Also dealt with are problems of
measurement in research of this kind. It seems likely
that much of the divergence in previous studies is due to
the type of measure used, that is, the overall rate of

responding, which includes both the post-reinforcement pause and the running rate. These may be affected differently by the magnitude of reinforcement, and when they are averaged the extent of the changes in the two may be masked. The experiments reported here revealed major effects not reflected fully in the overall rate.

EXPERIMENT 6

It has frequently been reported that IRTs following reinforcement on DRL schedules are longer than those IRTs which follow non-reinforced responses, even when response bursts, which only occur after non-reinforced responses, are not taken into account (Carter and Bruno, 1968 a; MacDougall et al., 1969; Weiss, 1970). One possible explanation of this finding is that the shorter IRTs following non-reinforced responses are the result of the emotional or frustrative effects of non-reward (Amsel, 1958; 1962 - and see Chapter 6).

It was shown in Experiments 1-5 that both reinforced and non-reinforced responses have stimulus properties on DRL schedules and it was suggested that the reinforcer

may have more intense, and hence more effective, stimulus properties than a non-reinforced response. The difference in the duration of IRTs following reinforced and non-reinforced responses may thus be due to stronger inhibitory after-effects of the reinforcer rather than to frustration following non-reinforced responses.

This experiment attempted to test the inhibition hypothesis by manipulating the intensity of stimulation at reinforcement. The concentration of the reinforcer was systematically varied on different DRL schedules.

Subjects

Two male albino rats (112 and 113) were used. Both subjects had previous experience of DRL schedules (in Experiments 2 and 5).

Procedure

Animal 112 was placed on two-component DRL 10-20 and Animal 113 on DRL 20-20, for a minimum of 45 daily 1-hr sessions. Testing began when the formal stability criterion was met and visual inspection of the records showed that responding was stable. In testing, a different reinforcer concentration was used in each of

four successive sessions - one of these concentrations
was the same as that used in training. Table 8 shows
the concentrations used during training and in test
sessions and also the order in which the concentrations
were presented.

Following the test sessions the schedule parameters
were changed. Animal 112 was now placed on DRL 10-10
and Animal 113 on DRL 20-10 for a minimum of 25 sessions.
When the formal stability criterion was then met and
visual inspection of the records showed that responding
was stable, testing recommenced as before. The details
are given in Table 8.

Results

Figure 36 shows the distributions of IRTs for
the t_1 and t_2 components obtained with each concentration
on each schedule. Corresponding overall frequency
distribution of IRTs are shown in the Appendix (Figure
74). With all reinforcer concentrations, the two
schedule components maintained distinct control of the
temporal distribution of responses. In every schedule
used, the concentration of the reinforcer affected the
IRT distributions in the t_1 component. The proportion of

TABLE 8

Order of exposure to the experimental conditions
(listed top to bottom), order of test concentrations
(listed left to right), and the number of sessions on
each concentration, for individual subjects.

SUBJECT	SCHEDULE (SEC)	NUMBER OF SESSIONS	BASELINE	ORDER OF TEST PRESENTATIONS			
			CONCENTRATION (%)				
112	10-20	45	20	5	20	10	40
	10-10	26	20	40	10	5	20
113	20-20	47	30	50	10	70	30
	20-10	27	30	30	70	50	10

Figure 36. Relative frequencies
of IRTs, with different reinforcer
concentrations. The distributions
are shown separately for the t_1 and
t_2 components. The data are from
the test sessions on each schedule
for each subject.

ANIMAL 112

ANIMAL 113

RELATIVE FREQUENCY (%)

INTERRESPONSE TIMES IN SECONDS
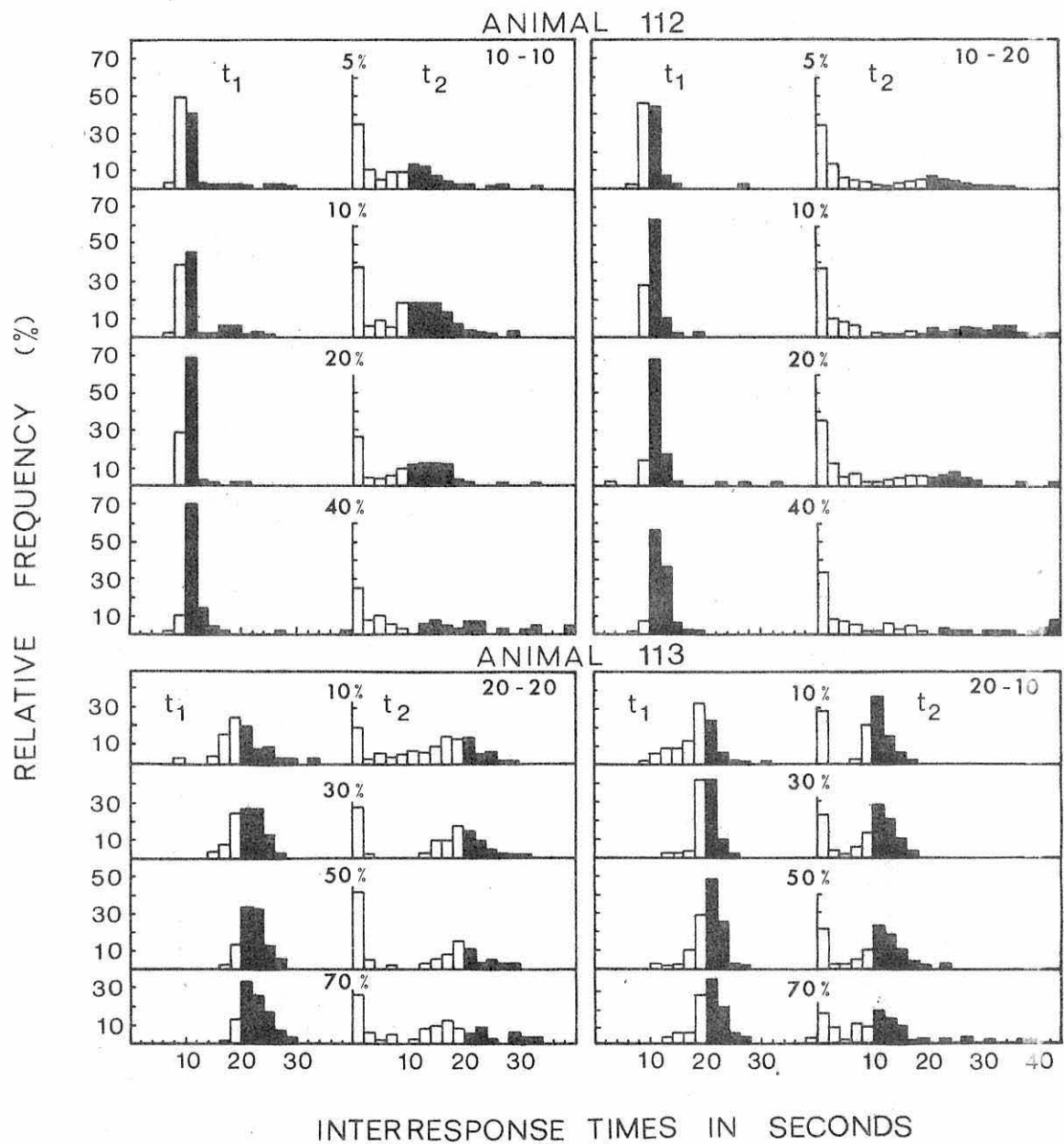
non-reinforced IRTs declined as a function of the
reinforcer concentration, with a corresponding
increase in the proportion of reinforced IRTs.

The effect of reinforcer concentration on
responding in the t_1 component is shown in Figure 37
which presents for each subject the median and inter-
quartile range of IRTs on t_1. In every schedule the
median IRT increased as a function of the reinforcer
concentration, the increase continuing beyond the
minimum IRT requirement. Moreover this effect persisted
even when further increases in the durations of the IRTs
did not result in a higher rate of reinforcement. Figure
38 shows that the rate of reinforcement increased as a
function of the concentration up to 50%, but when the
concentration was above that there was no corresponding
increase in the rate of reinforcement.

Figure 39 shows the efficiency of performance
as a function of reinforcement concentration. The main
effect of concentration was upon responding in t_1, that is,
upon the IRTs initiated by reinforcement; efficiency in
t_1 was a direct function of reinforcement magnitude.
Efficiency on the t_2 component showed no systematic
relationship to the concentration of the reinforcer. This

Figure 37. The median and
interquartile range of the durations
of the IRTs on the t_1 component,
as a function of the reinforcer
concentration. The horizontal
dotted lines show the minimum IRT
criteria above which reinforcement
occurred. The data are from the
test sessions on each schedule for
each subject.
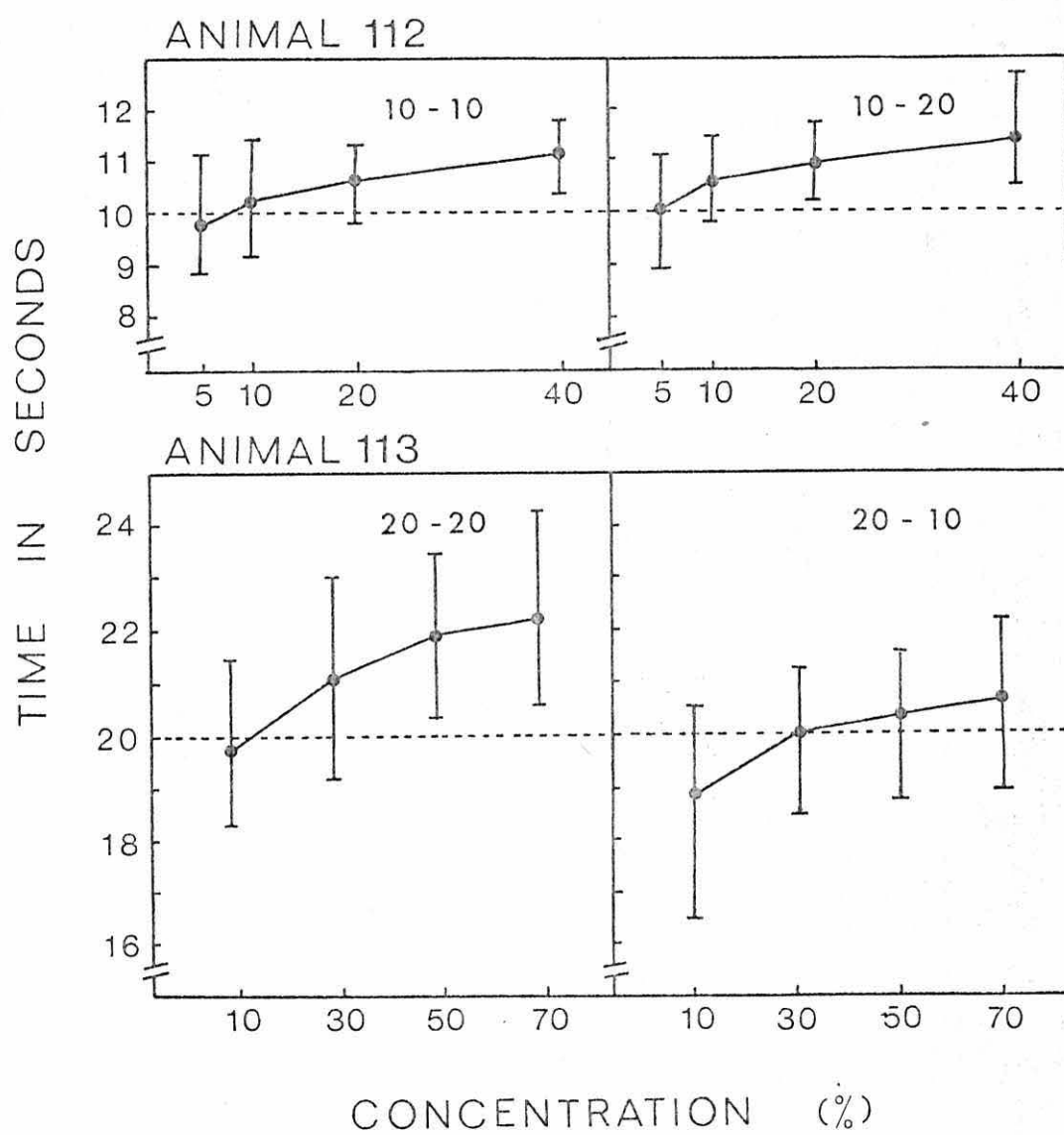
Figure 38. The rate of
reinforcement in the t_1 component
as a function of reinforcer
concentration. The data are from
the test sessions on each schedule
for each subject.
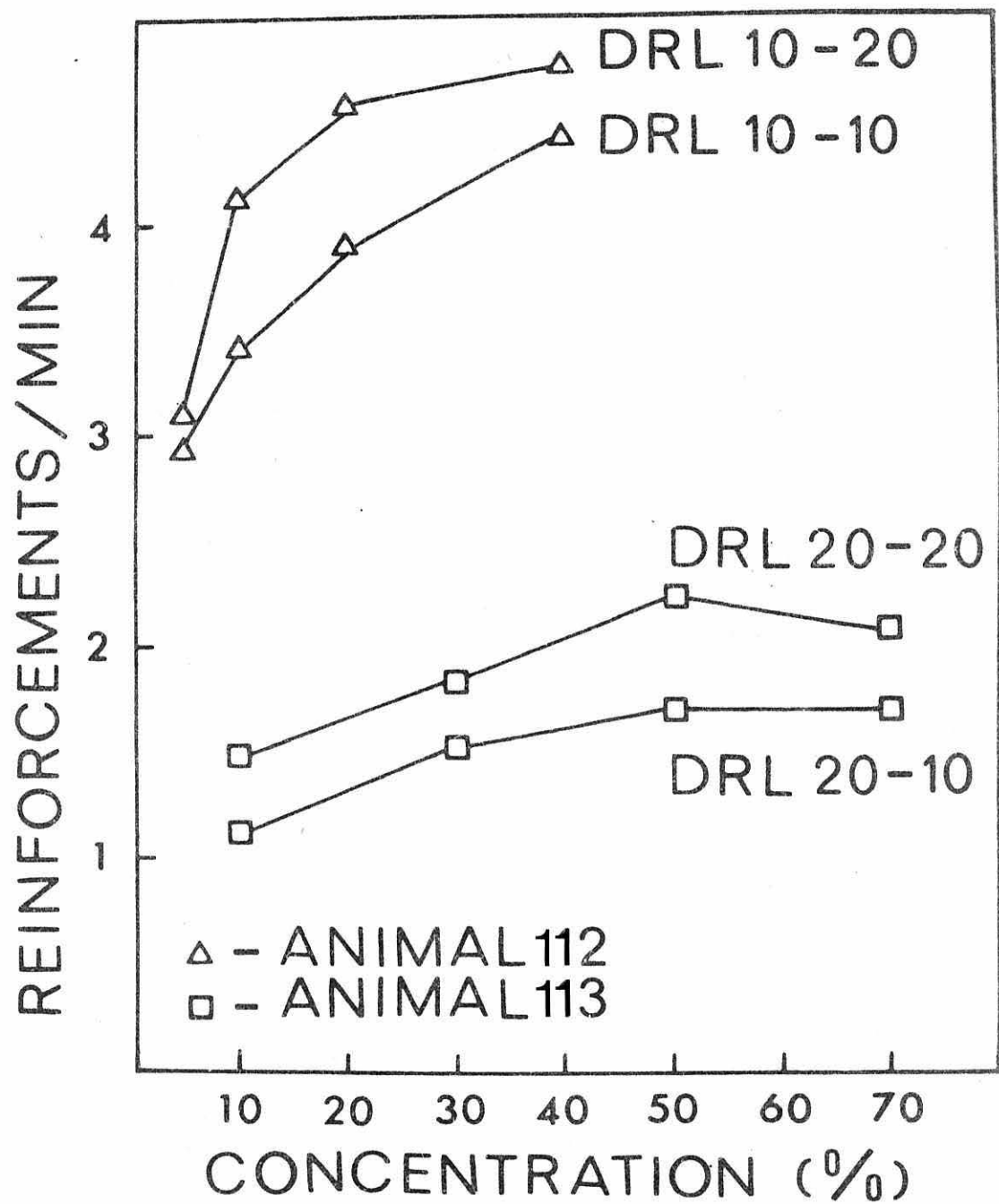
Figure 39. Efficiency of performance
as a function of reinforcer
concentration. Overall efficiency is
shown (open squares), as well as
efficiency on the t_1 (filled circles)
and t_2 (open circles) components. The
data are from the test sessions on
each schedule for each subject.
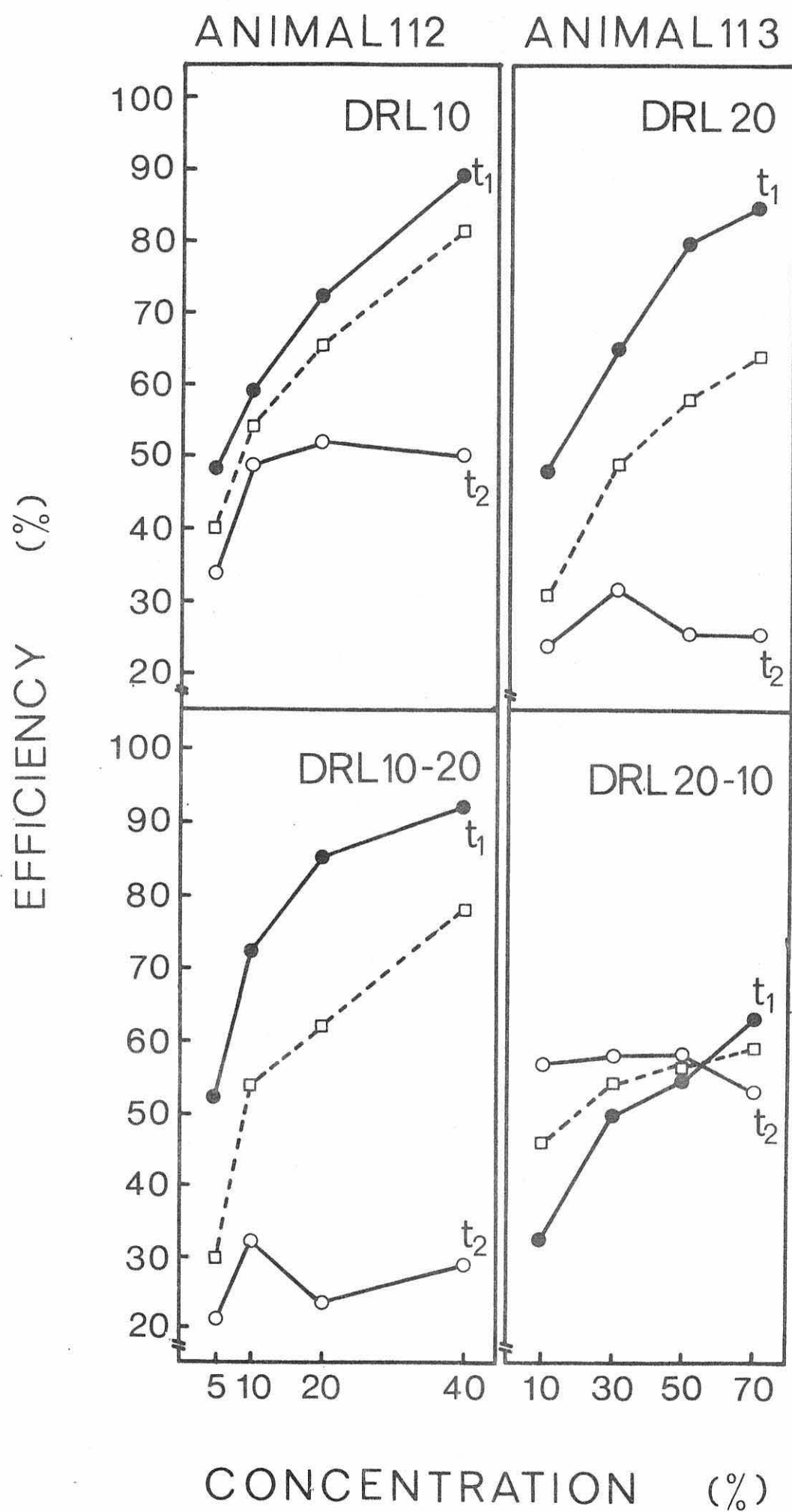
was the case even in the DRL 20-10 schedule where
the contingency was more favourable after a non-
reinforced response than after reinforcement, reflected
in the greater efficiency of performance on the t_2
component with lower reinforcer concentrations; with
increases in the concentration, however, only the
efficiency on t_1 increased, surpassing the efficiency
on t_2 when the concentration was 70%.

Though efficiency on t_2 did not change
systematically, overall efficiency increased as a function
of reinforcer concentration. In all the schedules, the
relationship between the overall efficiency of performance
and reinforcer concentration was a reflection of the
effect upon responding in the t_1 component. This was
also the case for the response rate functions (Figure
40); the rate of responding in t_1 and the overall rate
consistently declined as a function of reinforcer
concentration.

Another aspect of performance affected by reinforcer
concentration was the number of successive reinforcements
which occurred without interruption by non-reinforced
responses. The number of reinforcements in each
successive "run", in all the test sessions, is shown in

Figure 40. The response rate as a function of reinforcer concentration. Overall rate is shown (open squares), as well as the rate on the t_1 component (filled circles) and t_2 (open circles) components. The data are from the test sessions on each schedule for each subject.

ANIMAL 112   ANIMAL 113

DRL 10   DRL 20

DRL 10-20   DRL 20-10

RESPONSES PER MINUTE
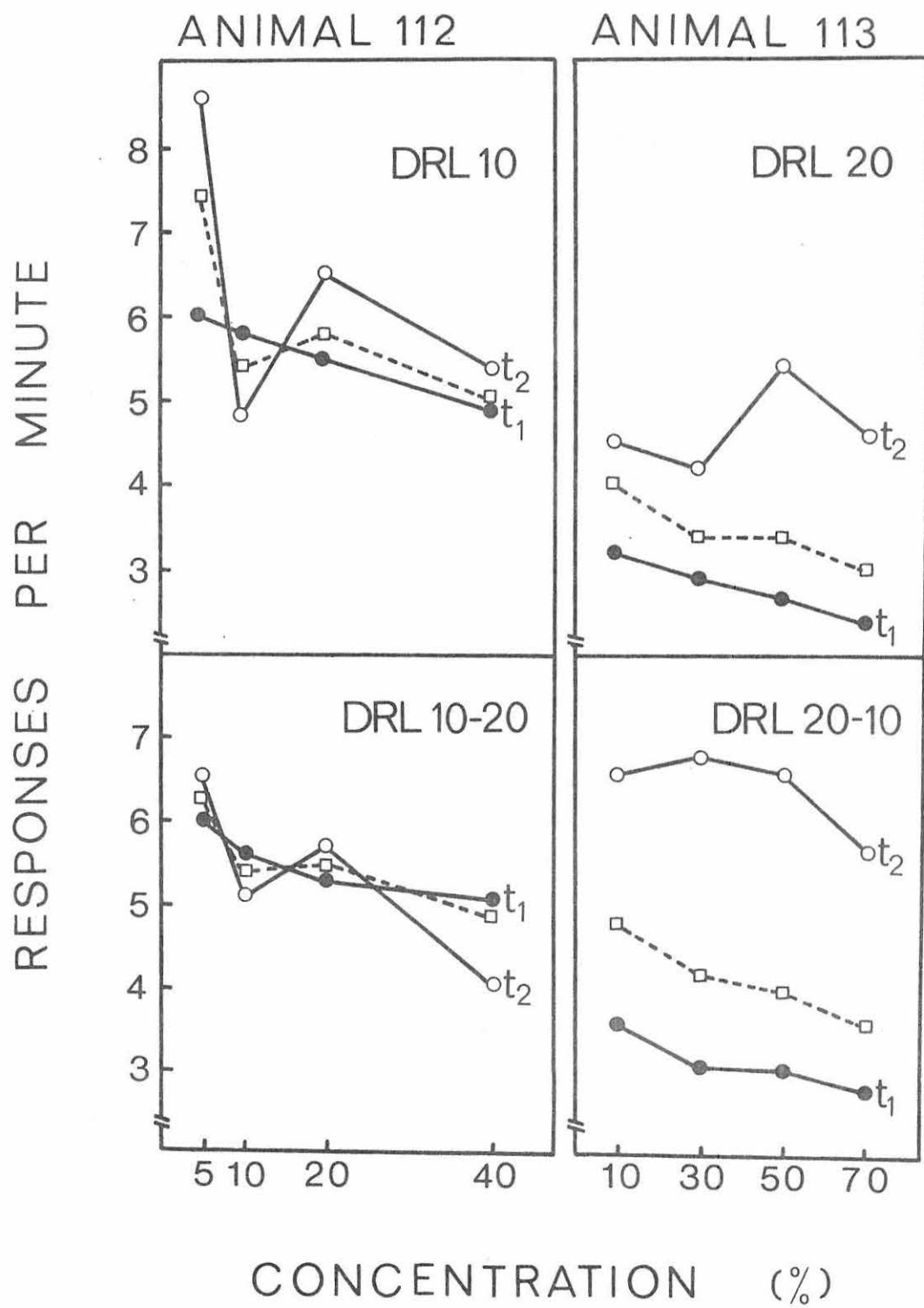
CONCENTRATION   (%)

Figure 41. The runs tended to be longer when they occurred in the earlier part of a session than later in a session; the longest runs occurred on the highest concentrations.

Discussion

The main effect of the reinforcer concentration was upon IRTs in the t_1 component, i.e., IRTs which immediately followed reinforcement. The increase in the duration of these IRTs as a function of reinforcer concentration, and the absence of any systematic effect of concentration upon IRTs in the t_2 component, support the suggestion that the reinforcer has inhibitory after-effects on DRL which are related to the magnitude of the reinforcing stimulus. These findings cannot be explained in terms of conventional frustration theory (cf. Amsel, 1958; 1962).

These results are also in accord with the notion that longer IRTs occur after reinforcement than after non-reinforced responses on DRL because of the greater intensity of stimulation at reinforcement, which serves as a more effective inhibitory stimulus.

Figure 41. Number of reinforcements
which occurred in sequence, without
interuption by non-reinforced responses.
These "runs" of reinforcements are
shown in the consecutive order in which
they occurred in each test session for
each subject.
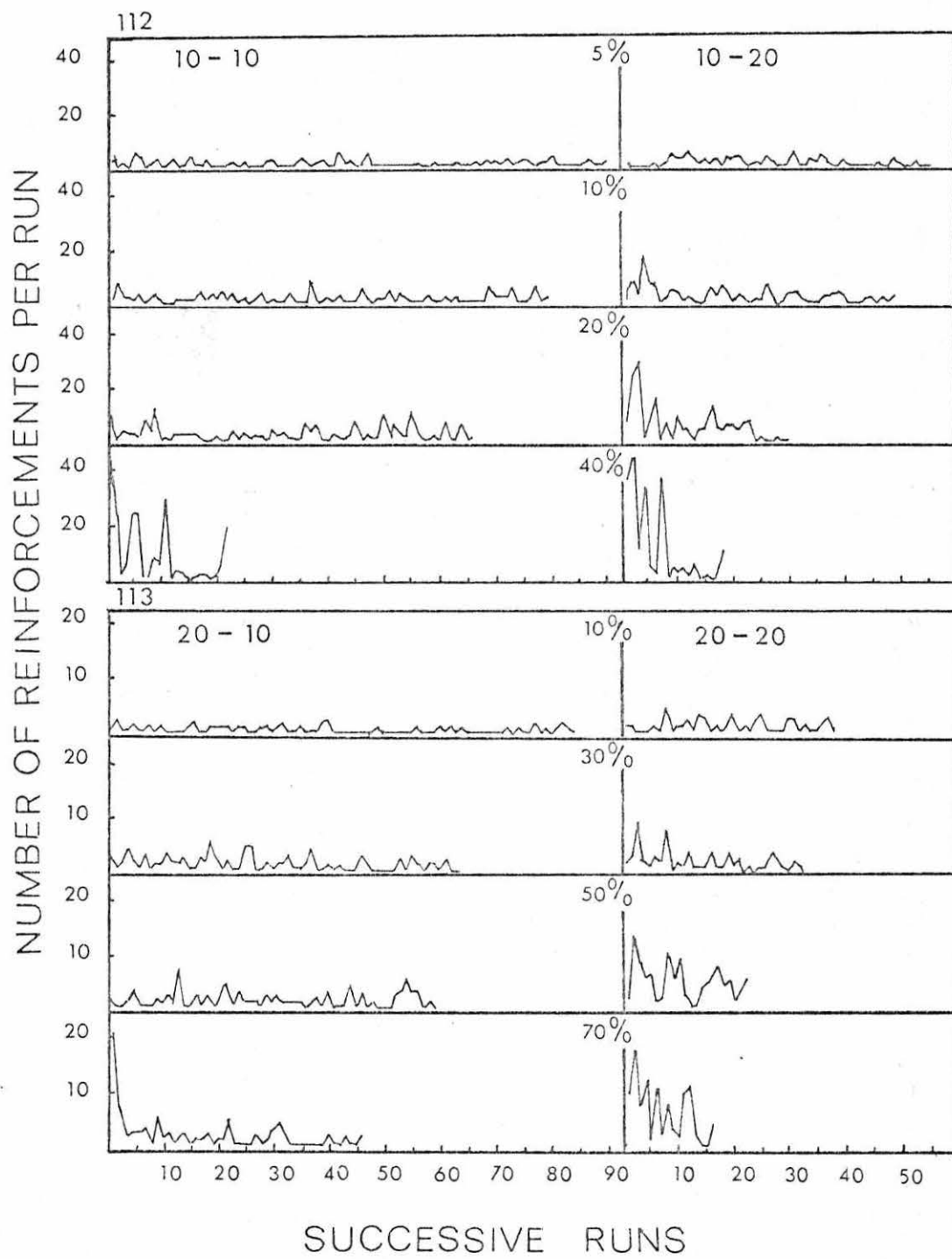
Though the present findings do not appear to
be in agreement with those of Beer and Trumble (1965),
the latter study, which used a two-lever response-
initiated DRL, excluded from analysis the IRTs which
immediately followed reinforcement; using such an
analysis the inhibitory after-effects of reinforcement
could not be shown. Beer and Trumble, who reported
a decrease in the duration of IRTs which occurred
between 1st lever-2nd lever sequences as a function
of reinforcement magnitude, also presented differential
stimuli associated with each magnitude; this latter
aspect of the procedure is known to have a rate-enhancing
effect on performance on other schedules (e.g., Keesey
and Kling, 1961; Jensen and Fallon, 1973; Meltzer and
Howerton, 1973). Thus, although the present results
show longer IRTs after higher concentrations of the
reinforcer and show no rate-enhancing effect of
reinforcement magnitude, they are not necessarily
incompatible with the findings of Beer and Trumble (1965),
since there are substantial procedural differences in
the two studies.

Collier and Myers (1961) suggested that longer
pauses following greater magnitude of reinforcement on
FI schedules might be due to "momentary satiation", which
would serve to increasingly depress responding following

reinforcement as the experimental session progressed.
Fowler and Notterman (1974) have argued that similar
factors depress CRF responding on higher reinforcement
magnitudes. A satiation account might also be put
forward to explain the longer t_1 IRTs which followed
higher concentrations in the present experiment.
According to the data on "runs" of successive
reinforcements, however, the longer IRTs following
greater magnitudes of reinforcement cannot be attributed
to a satiation effect. In satiation, the IRTs would be
expected to become longer in the latter part of a session,
resulting in longer sequences of reinforcement as the
session proceeded. The present results showed no such trend;
in fact, an opposite tendency was present, with longer
"runs" occurring in the early part of a session.

It is also possible that increased consummatory
behaviour may have been responsible for the increase
in the duration of IRTs following higher concentrations.
If, for example, on DRL 10-10 it took approximately
10 sec to consume the 20% concentration, then the 40%
concentration might take longer to consume. This
explanation is unlikely for the following reasons:
(i) A small amount of milk (0.05 ml) was used as the
reinforcer and the amount was held constant throughout
the experiment. (ii) Similar reinforcer concentrations

yielded very different IRTs following reinforcement, depending on the value of the DRL requirement in t_1; IRTs on DRL 10-10, at all concentrations, were in the region of 10 sec, while on DRL 20-20 IRTs were in the region of 20 sec. This suggests that the length of IRTs on these schedules was not controlled by the duration of the consummatory behaviour. (iii) Observation of the animals during experimental sessions showed that the time between responses was not spent consuming the reinforcer but most often in other activities such as biting the lever, biting the corners of the recess and moving around the experimental chamber.

Though much of the evidence indicates that the behavioural effects observed in the present experiment were due to inhibitory after-effects of the reinforcer, the results also provide support for an alternative explanation which does not involve the notion of inhibition. It has been argued (Stebbins et al., 1959; Di Lollo et al.,1965; Notterman and Mintz, 1965; Walker, 1969) that increasing the magnitude of reinforcement enhances the temporal patterning or precision of performance. Thus the finding that IRTs are longer on the higher concentrations may indicate a better discrimination

of the temporal contingencies. That the longer IRTs
resulted in an increase in reinforcement rate and
efficiency on the DRL schedules does suggest that the
effect of increasing reinforcement was to enhance
the precision of performance.

The duration of the median IRTs for Animal 113,
however, increased consistently as a function of
concentration, while reinforcement rate did not increase
beyond 50%. This indicates that the subject paused
too long following reinforcement, preventing maximisation
of reinforcement frequency. This result would not
appear to represent a greater accuracy of performance
as a function of reinforcement magnitude, and is more
easily explained by the inhibitory hypothesis.

It is not possible, on the basis of the performance
of this one animal, to rule out an account of the present
results in terms of an improved discrimination of the
contingencies when reinforcement magnitude was increased.
The increased rate of reinforcement which followed as a
consequence of longer IRTs on most concentrations raises
the possibility that this, rather than any inhibitory
properties of the reinforcer, may have been responsible
for the increased frequency of longer IRTs.

EXPERIMENT 7

In attempting to assess the inhibitory after-
effects of reinforcement magnitude on DRL responding,
it was noted that longer IRTs on this schedule
frequently increased the rate of reinforcement. It
was thus not clear whether reinforcement magnitude
operated in such a way as to enhance performance, so
that reinforcement was maximised, or whether the
primary effect was to inhibit responding immediately
following reinforcement, regardless of the effects upon
reinforcement rate.

This experiment investigated the effects upon
performance of manipulating the concentration of the
reinforcer on a conventional FI schedule. On this
schedule, longer pausing does not result in an increased
frequency of reinforcement, and, as long as it does not
extend beyond the value of the fixed interval, the
duration of the post-reinforcement pause does not
affect the rate of reinforcement.

Subjects

Three male albino rats (122, 123 and 124) served
as subjects. They had previous experience of a response-
initiated FI schedule to be described in Experiment 8.

Apparatus

To facilitate within-session changes in the
concentration of the reinforcer, the milk reinforcer
was contained in four separate containers situated
below the dipper mechanism; these containers were
rotated via the external scheduling equipment. A
detailed description of the apparatus is presented
in Chapter 4.

Procedure

The subjects were placed on an FI 60-sec
schedule for 40 daily 1-hr sessions prior to testing.
After 40 sessions the formal stability criterion was
met and visual inspection of the records showed that
responding was stable. The concentration of the
condensed milk was 30% throughout the training phase
but the milk containers were rotated after every six
reinforcements so that the animals might habituate
to the sound of the motor/gearbox.

Testing: The same schedule was in operation as during
training. Four different reinforcer concentrations
10%, 30%, 50%, 70%, were presented in blocks of six
reinforcements; the order of the blocks was random,

with the constraint that in a session each block occurred
only once. 8 test sessions were conducted, each
consisting of 24 reinforcements.

Results

Figure 42 shows the effects upon performance
of the preceding reinforcer. For all subjects, both
the duration of the mean post-reinforcement pause and
the running rate, increased linearly as a function of
the concentration of the reinforcer. The effects on
overall response rate were slight; overall rate was
inversely related to concentration for Animal 123 and
declined at 70% for Animals 122 and 124.

The median and interquartile range of the post-
reinforcement pause durations, as a function of
concentration, are presented in Figure 43. These data
show, in all cases, a consistent increase in the duration
of post-reinforcement pause as concentration was increased
and confirm the mean post-reinforcement pause/concentration
relation observed in Figure 42.

The mean duration of the post-reinforcement pause
as a function of ordinal position within a test block is
shown in Table 9. The duration of the post-reinforcement

Figure 42. FI: mean overall rate (left panel), running rate (centre panel) and post-reinforcement pause (right panel) as functions of concentration of the preceding reinforcement. Data were averaged across the test sessions for the three rats.
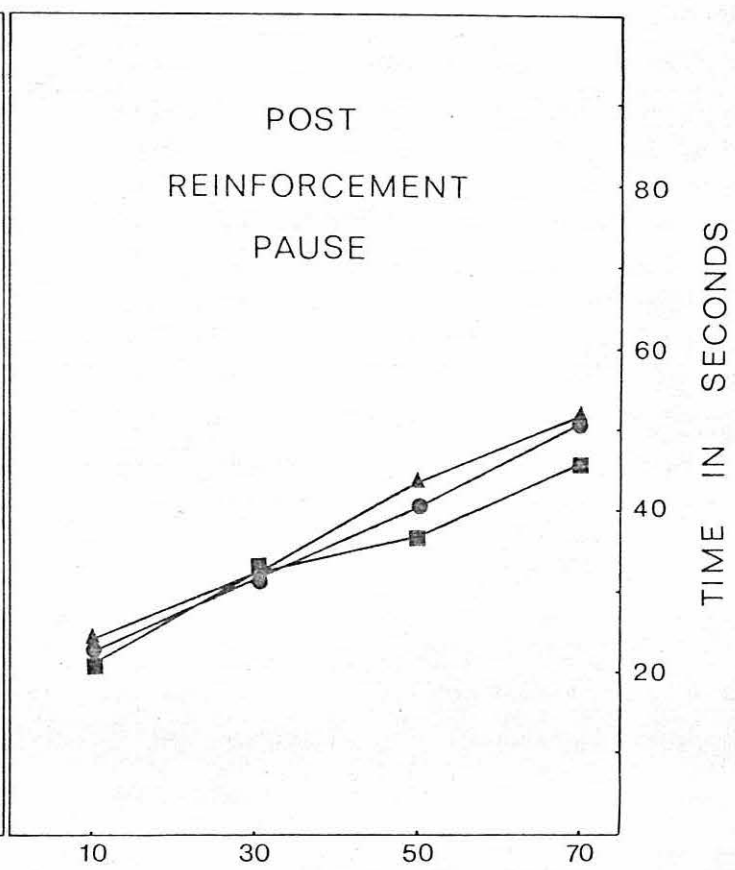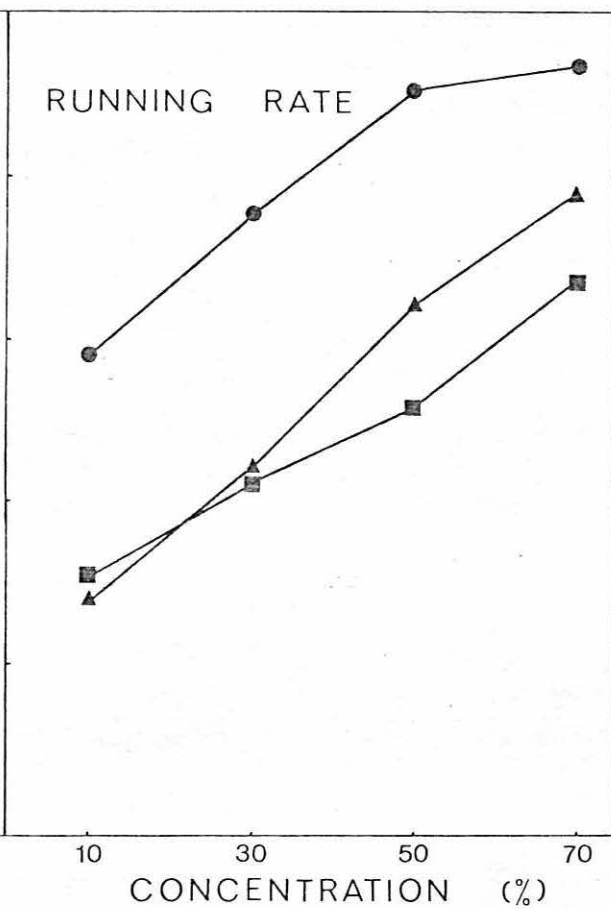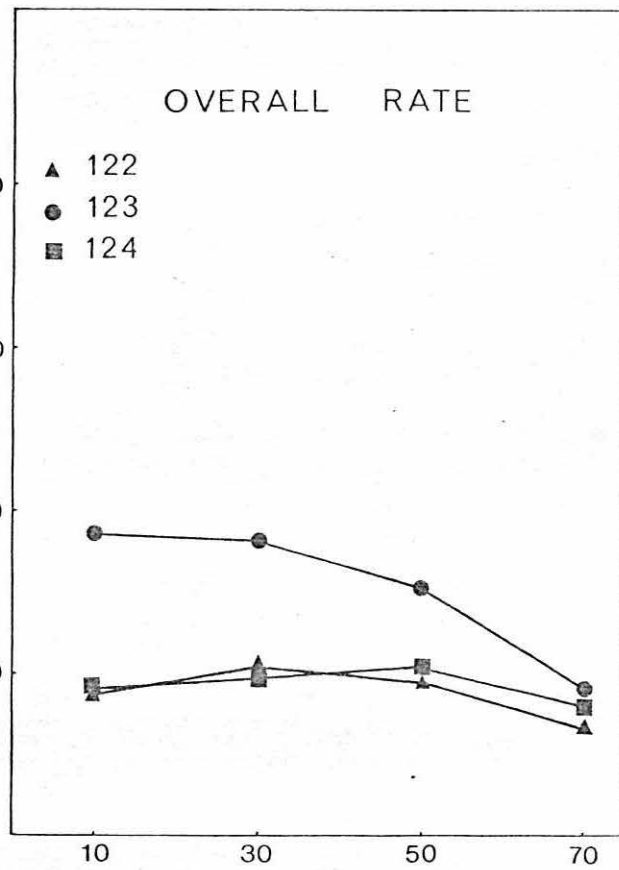
Figure 43. FI: the median and inter-
quartile range of the durations of the
post-reinforcement pauses as a function
of concentration of the preceding
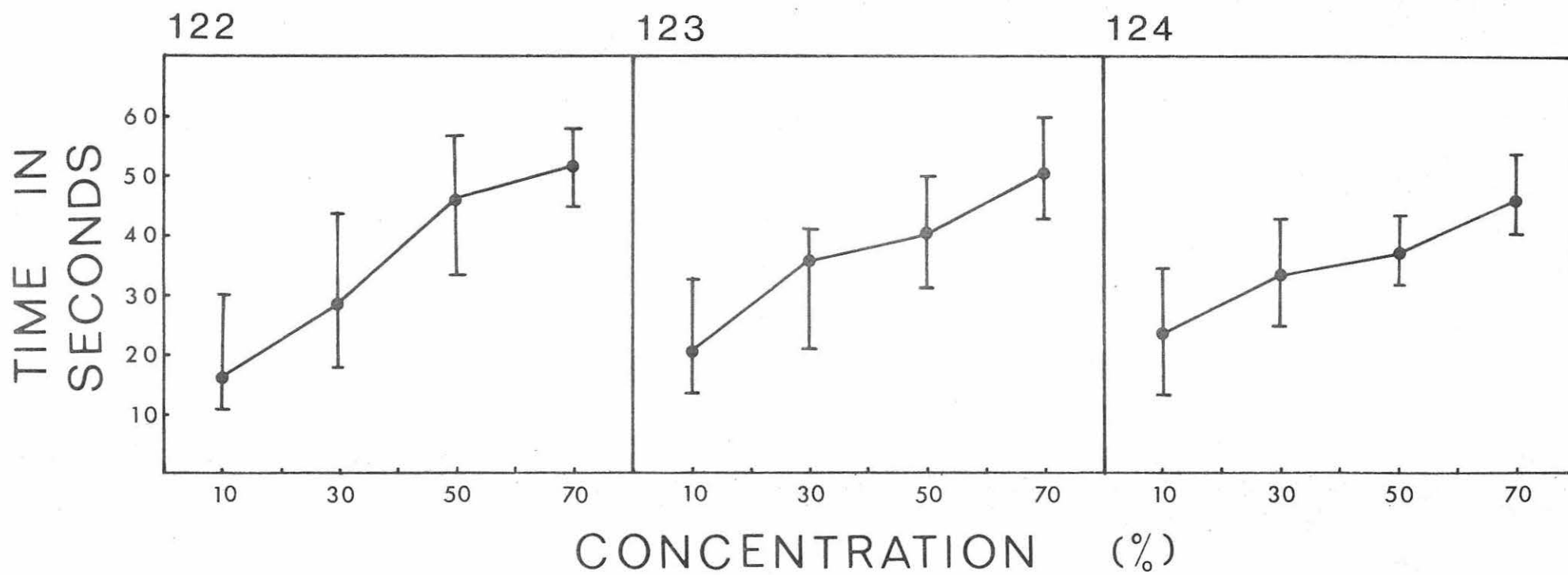reinforcement. Data are from the test
sessions for each subject.

TABLE 9

Mean duration of the post-reinforcement pause as a
function of the ordinal position in a block. Data
are from the test sessions.

| CONCENTRATION | ANIMAL | ORDINAL POSITION | | | | | |
		1	2	3	4	5	6
	122	21.5	17.8	25.9	13.6	27.8	21.4
10%	123	21.4	18.5	21.1	13.5	26.6	36.0
	124	30.6	16.3	18.0	21.4	25.3	34.4
	MEAN	24.5	17.5	21.7	16.2	26.6	30.6
	122	32.5	20.9	39.6	33.3	35.4	32.0
30%	123	34.4	37.6	28.3	25.4	27.9	31.4
	124	29.6	32.1	34.8	27.9	41.8	30.3
	MEAN	32.2	30.2	34.2	28.9	35.0	33.2
	122	37.3	44.0	42.6	42.6	47.5	46.5
50%	123	34.1	39.3	39.9	42.3	43.9	44.5
	124	37.4	35.9	32.1	40.6	33.3	42.4
	MEAN	36.3	39.7	38.2	41.8	41.6	44.5
	122	54.6	51.0	53.9	50.1	51.9	49.5
70%	123	48.3	48.3	51.6	43.5	54.6	58.6
	124	42.4	49.6	45.9	46.8	46.2	45.1
	MEAN	48.4	49.6	50.5	46.8	50.9	51.1

pause changed appropriately following the first presentation of a new concentration in a block, and there was no ordinal effect within any one test block.

Figure 44 shows the median and interquartile range of running rates in each fixed interval as a function of the preceding reinforcer concentration. This shows a consistent direct relation between running rate and concentration, consistent with the mean running rate data presented in Figure 42. Evidence is also shown here of an increase in the variability of response rate on the higher concentrations.

Discussion

The finding that the duration of the post-reinforcement pause increased as a function of reinforcer concentration and that the duration changed appropriately following the first presentation of a new concentration, indicates that it was the concentration of the reinforcer initiating an interval which significantly affected the duration of the subsequent post-reinforcement pause.

Figure 44. FI: the median and interquartile range of the running rates in each fixed interval as a function of concentration of the preceding reinforcement. Data are from the test sessions for each subject.

RESPONSES PER MINUTE

CONCENTRATION (%)
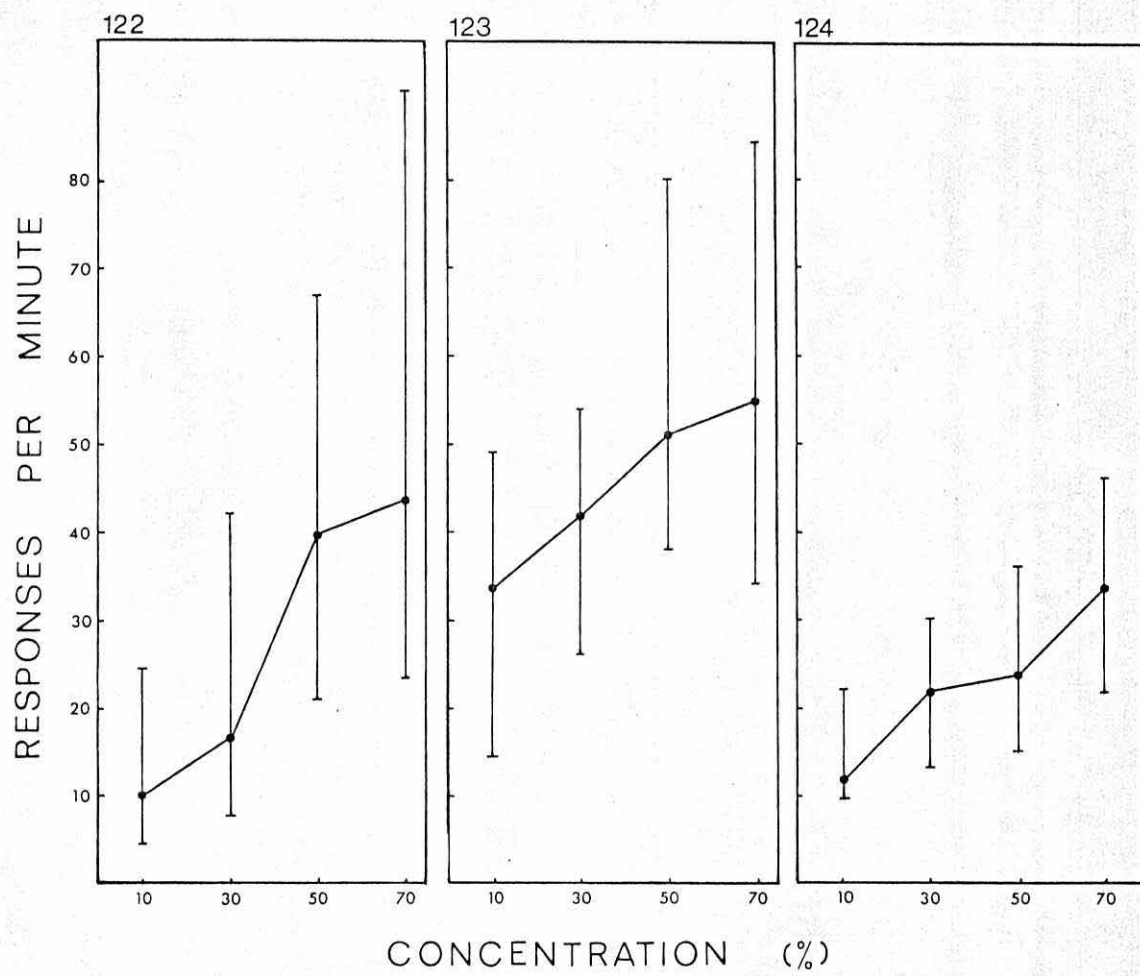
These results are in agreement with those of
Staddon (1970 a) who found that on an FI 60-sec schedule
with pigeons, longer reinforcer durations resulted in
longer post-reinforcement pauses. Similar depressive
effects of the preceding reinforcer duration were
observed with rats, on a multiple FI FI schedule, by
Jensen and Fallon (1973). Meltzer and Howerton (1973)
have also reported a lower response rate early in the
fixed interval when the number of pellets presented
as the reinforcer in the preceding interval was increased.

The direct relationship between post-reinforcement
pause duration and reinforcement magnitude, reported
in this experiment, is similar to that observed on DRL
schedules in Experiment 6.. In the present experiment
however, the effect of an identical range of reinforcement
concentrations as was used in the DRL study, was
considerably greater, e.g., mean post-reinforcement pause
durations of up to 50 sec occurred on the 70% concentration
as compared with IRTs after reinforcement on DRL 20-20
of approximately 22 sec on the 70% reinforcer.

Staddon (1970 a) reported that the running rate
of pigeons decreased as a function of the duration of
the preceding reinforcer; this is in direct contrast
with the present results which show that when the
concentration of the reinforcer was increased, the
subsequent running rate also increased. This apparent
discrepancy will be discussed later in the present
chapter.

Even though the effects of reinforcement magnitude
on both running rate and the duration of the post-
reinforcement pause were substantial, they were not
reflected in the overall rate of responding, since in
this measure an increase in the running rate tends to
be cancelled out if accompanied by an increase in the
duration of the post-reinforcement pause.

It was argued that when reinforcement magnitude
was increased on the DRL schedules, the increased
frequency of longer pauses after reinforcement, i.e.,
IRTs on the t_1 component, may have been partly due to
the increase in reinforcement rate which followed longer
pauses. In the present experiment the longer pauses
which followed the reinforcer had no effect on the rate of
reinforcement. The present results cannot then be

interpreted in terms of a better reinforcement
maximisation strategy with higher reinforcer concentrations.
They may, however, like the DRL data, reflect an
enhanced discrimination of the temporal contingencies
following greater magnitudes of reinforcement since
fewer responses occurred as a function of reinforcement
magnitude in that part of the fixed interval in which
reinforcement was never available.

EXPERIMENT 8

On an FI schedule each interval is usually timed
from the preceding reinforcement, and after the completion
of each interval the first response is reinforced. On
a response-initiated FI (tand FR 1 FI) schedule, on the
other hand, the interval is initiated by the first response
after reinforcement. Chung and Neuringer (1967) and Shull
(1970 a) have found that pigeons produce relatively long
post-reinforcement pauses on this schedule and that these
pauses are an increasing function of the FI value. The
running time, i.e., time from first response to reinforcement,
approximates the FI value, while there is variation in the
post-reinforcement pause, and consequently in the time
between reinforcements.

On a tand FR 1 FI schedule the shorter the post-reinforcement pause the sooner the next reinforcement becomes available. If greater magnitude of reinforcement enhances the accuracy of performance (Stebbins et al., 1959; Di Lollo et al., 1965; Notterman and Mintz, 1965; Walker, 1969), an inverse relationship would be expected between the concentration of the reinforcer and the duration of the post-reinforcement pause on this schedule; if, however, the after-effect of the reinforcer is inhibitory, higher concentrations should be followed by longer post-reinforcement pauses. This was investigated in the present experiment.

Subjects

Three naive male albino rats (122, 123, and 124) served as subjects.

Procedure

Lever-pressing responses were shaped, and after 30 reinforcements on CRF, the subjects were placed on a tand FR 1 FI 60-sec schedule for 50 sessions. After 50 sessions the formal stability criterion was met and visual inspection of the records showed that responding was stable. Testing then began. The concentration of the condensed milk was 30% during training; the milk containers

were rotated every six reinforcements so that the
animals might habituate to the sound of the motor-
gearbox.

Testing: Eight test sessions were conducted
in the same manner as in Experiment 7.

Results

Figure 45 summarises the data derived from this
experiment. The post-reinforcement pauses increased
markedly as the concentration of the reinforcer was
increased. The consistency of this relationship is shown
in Figure 46 which presents the median and interquartile
range of post-reinforcement pauses as a function of
reinforcement magnitude. These effects were consistent
within each block of concentrations; there were no
ordinal effects (Table 10).

The running rate data presented in Figure 45
show that for Animal 122, rate increased at 50% and 70%
(and slightly at 30%); for Animal 123 it increased at
30% and 50% but declined at 70%; for Animal 124, it
increased at 30% and declined at 50% and 70%. These
relationships are, in general, confirmed by the median
and interquartile range of running rates presented in
Figure 47.

Figure 45. Tand FR 1 FI: mean overall
rate (left panel), running rate (centre
panel) and post-reinforcement pause
(right panel) as functions of
concentration of the preceding reinforcement.
Data were averaged across the test sessions
for the three rats.
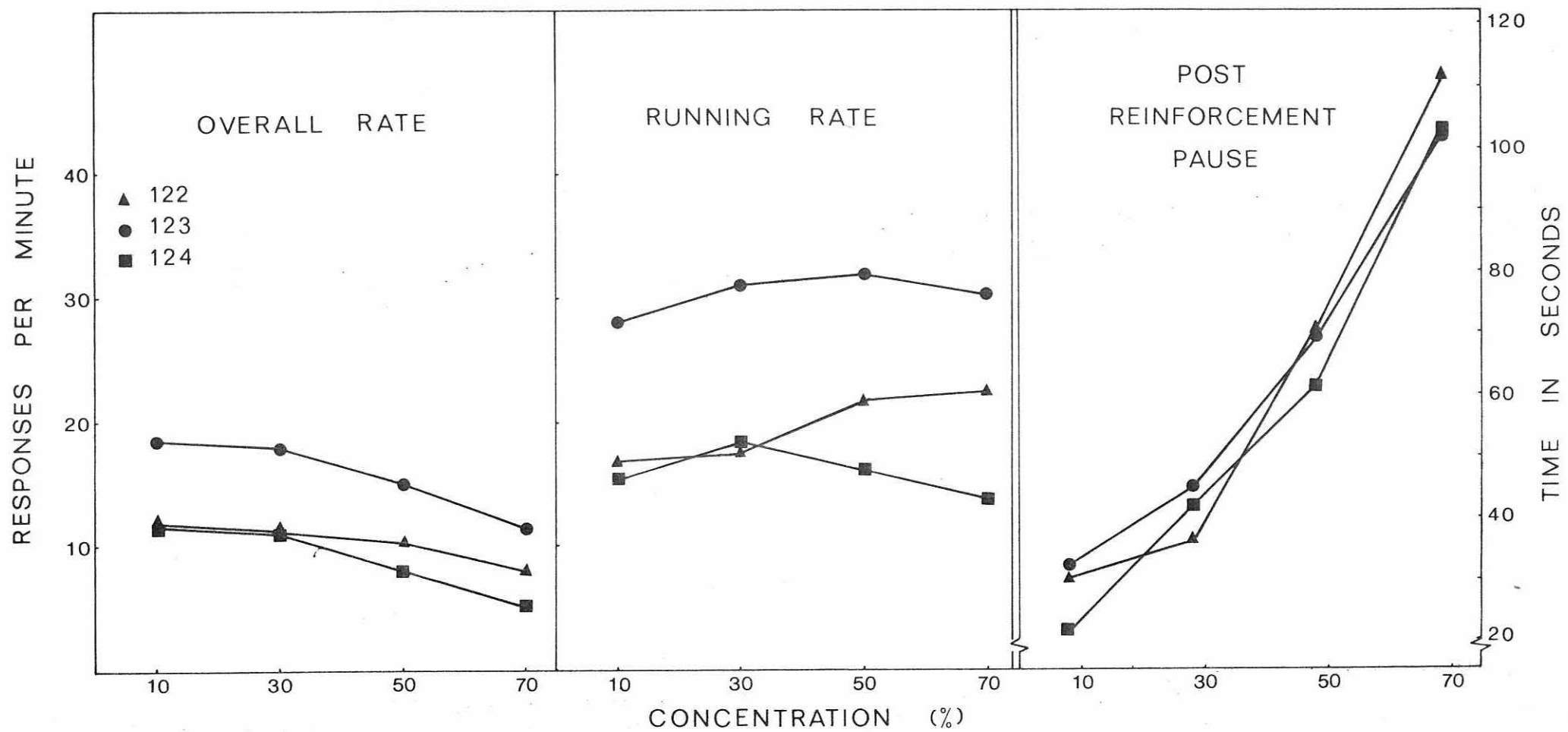
Figure 46. Tand FR 1 FI: the
median and interquartile range
of the durations of the post-
reinforcement pauses as a function
of concentration of the preceding
reinforcement. Data are from the
test sessions for each subject.
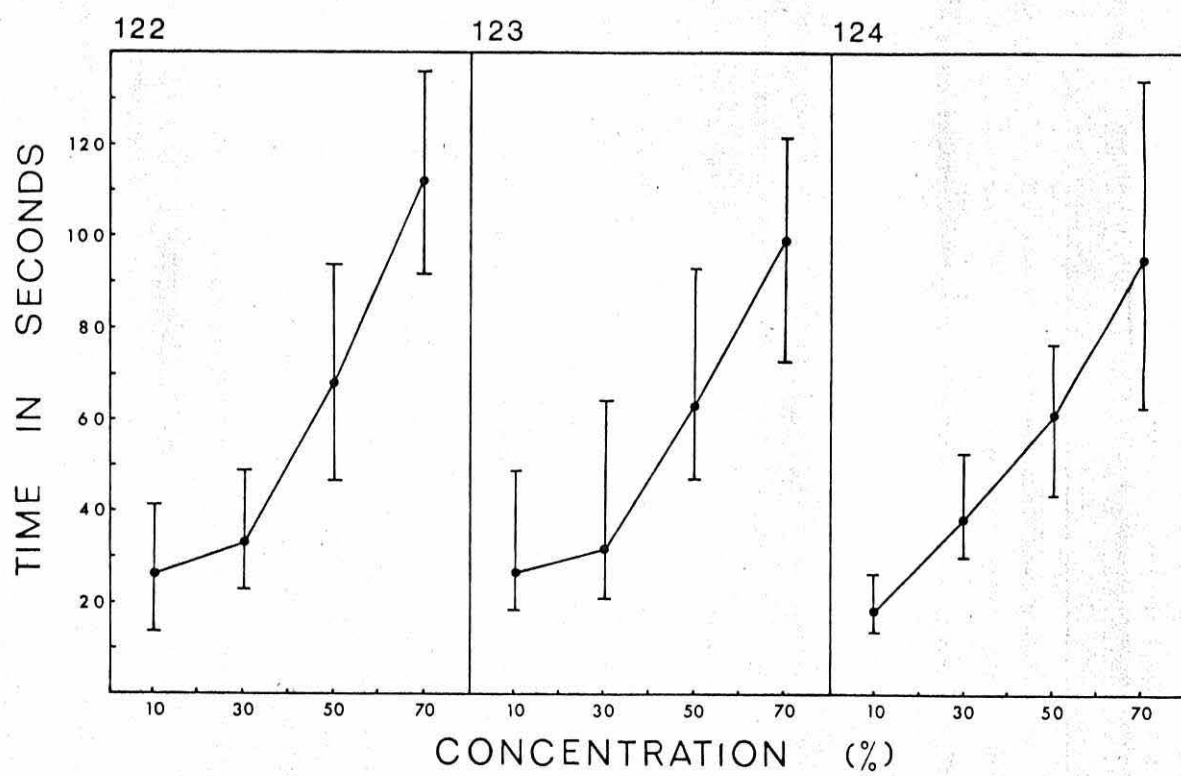
TABLE 10

Mean duration of the postreinforcement pause as a
function of the ordinal position in a block. Data
are from the test sessions.

| CONCENTRATION | ANIMAL | ORDINAL POSITION | | | | | |
		1	2	3	4	5	6
10%	122	34.4	23.8	32.4	23.1	38.3	26.3
	123	23.5	22.0	24.9	25.8	35.9	62.1
	124	21.8	13.4	19.1	23.1	18.1	32.1
	MEAN	26.6	19.7	25.5	24.0	30.8	40.2
30%	122	31.0	37.1	43.3	32.3	35.3	38.8
	123	44.9	43.1	31.5	39.1	51.1	58.4
	124	41.5	41.0	40.3	36.3	48.3	43.1
	MEAN	39.1	40.4	38.4	35.9	44.9	46.8
50%	122	66.3	52.3	79.9	69.1	86.5	65.3
	123	64.5	63.8	73.3	67.8	73.9	71.8
	124	58.0	56.5	62.5	58.6	64.4	68.0
	MEAN	62.9	57.6	71.9	65.2	74.9	68.4
70%	122	96.6	114.9	120.5	104.1	111.8	110.9
	123	87.0	104.6	104.5	102.6	120.5	90.0
	124	105.4	92.3	109.8	108.4	93.6	106.9
	MEAN	96.3	103.9	111.6	105.0	108.6	102.6

Figure 47. Tand FR I FI: the
median and interquartile range of
the running rates in each inter-
reinforcement interval as a function
of the concentration of the preceding
reinforcement.
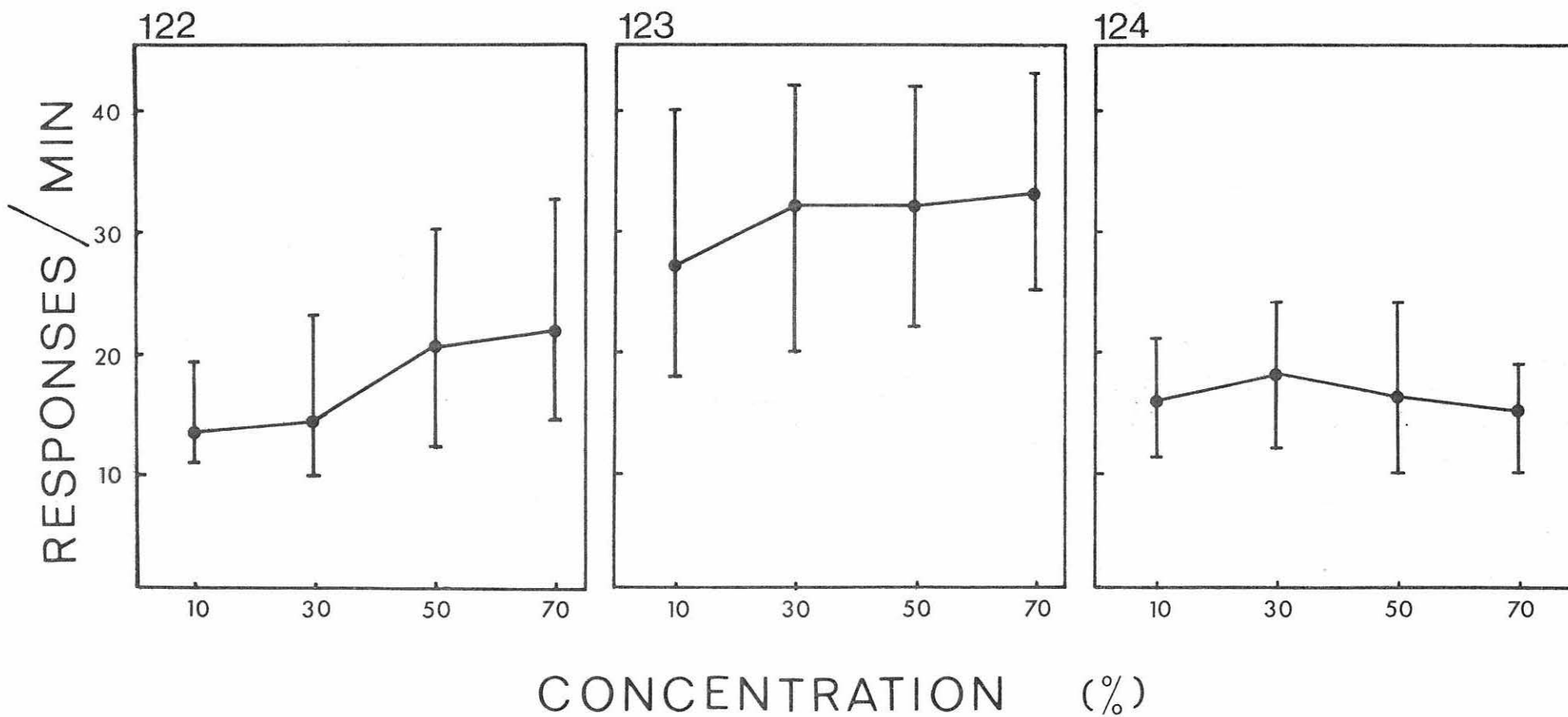
It was evident that the systematic but small changes in the overall rates (Figure 45) reflected mainly the effect upon the duration of the post-reinforcement pauses.

Discussion

Although on the response-initiated FI schedule the post-reinforcement pause delays the next reinforcement, higher concentrations of the reinforcer were followed by remarkably long post-reinforcement pauses, twice as long as those observed in the comparable FI schedule of Experiment 7. Consequently the reinforcement rates declined well below the maximum possible.

These findings cannot be said to reflect a greater temporal precision of performance following increased reinforcement magnitude. Neither, of course, can a reinforcement maximisation strategy be invoked to account for responding on this schedule.

The results clearly indicate that when the magnitude of reinforcement is increased, the after-effect that is enhanced is inhibitory.

In previous studies of performance on tand FR 1 FI
schedules (Chung and Neuringer, 1967; Shull, 1970 a)
the subjects (a) were pigeons and (b) had previous
experience of interval schedules before being placed on
the tand FR 1 FI. Prior exposure to interval schedules
might have established post-reinforcement pauses which
were retained "superstitiously" on the tand FR 1 FI
schedule, thus accounting for the presence of post-
reinforcement pauses which reduce reinforcement rate
on this schedule.

The subjects in the present experiment, which were
rats, were placed directly on tand FR 1 FI following
acquisition of responding on CRF. Substantial post-
reinforcement pauses developed in the course of training.
These results show that the characteristics of performance
previously observed on tand FR 1 FI schedules are not
confined either to pigeons or to subjects with previous
experience of interval schedules.

EXPERIMENT 9

Both FI and tand FR 1 FI schedules specifically involve temporal contingencies; the minimum inter-reinforcement time is fixed in the former, and in addition the running time is fixed in the latter. On an FR schedule, however, there is no explicitly programmed temporal contingency, and both the inter-reinforcement time and the running rate vary as consequences of the subject's behaviour. As in tand FR 1 FI, the inter-reinforcement interval is increased by longer post-reinforcement pauses.

Evidence was presented in Chapter 2 in support of the notion that the reinforcer in FR schedules has temporal inhibitory after-effects, similar to the inhibitory properties of the reinforcer on FI. This suggests that when the magnitude of reinforcement on FR schedules is increased, the inhibitory effects of the reinforcer may be enhanced.

Subjects

Three naive male albino rats (132, 133 and 141) served as subjects.

Procedure

After the lever-pressing responses were shaped, the subjects were placed on an FR 30 schedule for 30 daily 1-hr sessions, after which the formal stability criterion was met, and visual inspection of the records showed that responding was stable. The concentration of the condensed milk was 30% during training; the milk containers were rotated every six reinforcements so that the animals might habituate to the sound of the motor gearbox.

Testing: Eight test sessions were then conducted in the same manner as in Experiments 7 and 8.

Results

The mean overall rate, running rate and post-reinforcement pause duration for each subject, as a function of reinforcer concentration, are shown in Figure 48. The mean duration of the post-reinforcement pause was an increasing linear function of concentration. The consistency of this relationship is shown in Figure 49, which shows the median and interquartile range of post-reinforcement pause durations on each reinforcement magnitude. Table 11 shows that these effects were also consistent within each block of a given concentration.

Figure 48. FR: mean overall rate
(left panel), running rate (centre
panel) and post-reinforcement pause
(right panel) as functions of
concentration of the preceding
reinforcement. Data were averaged
across the test sessions for the three
rats.
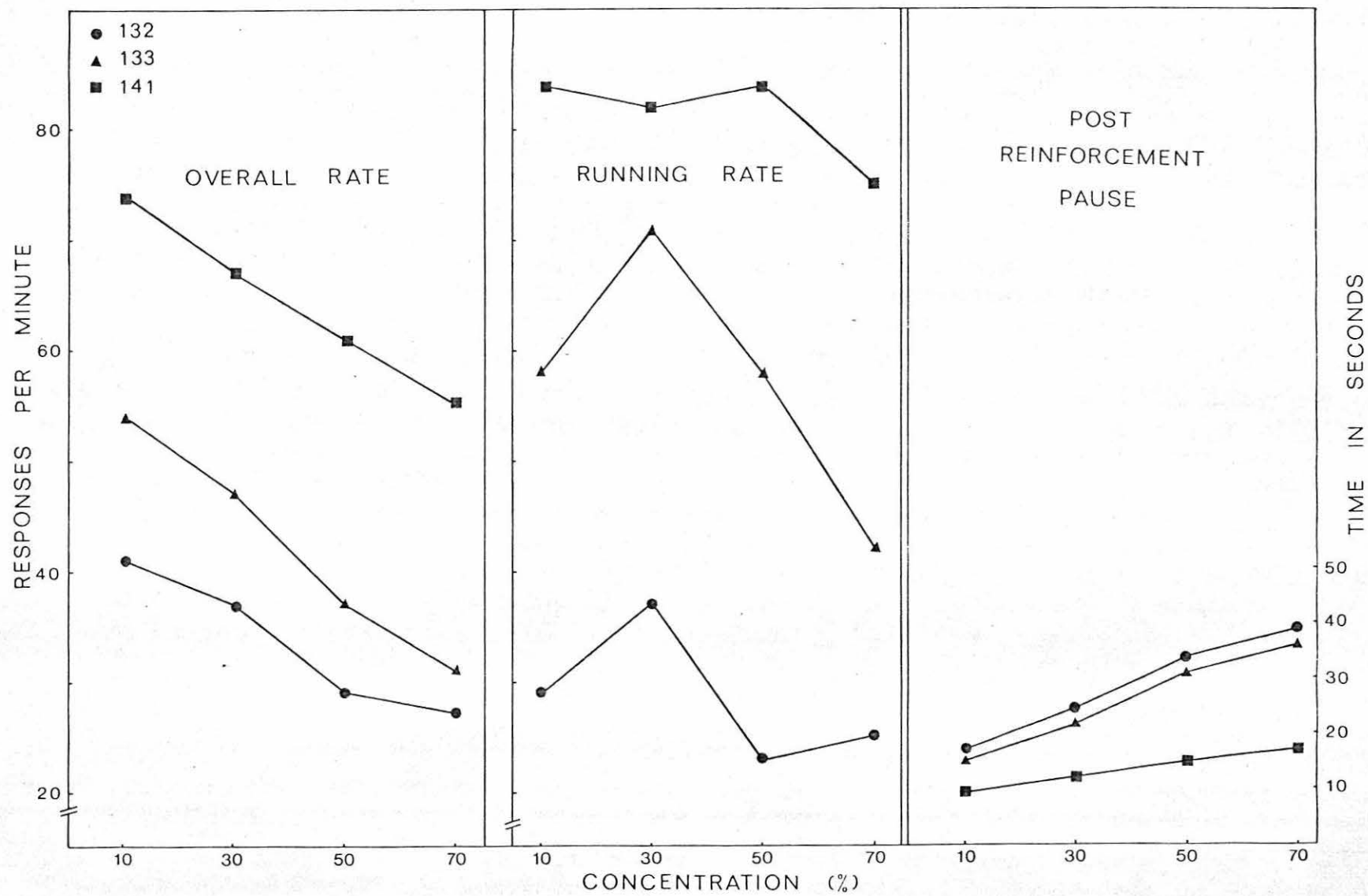
Figure 49. FR: the median and
interquartile range of the durations
of the post-reinforcement pauses as
a function of concentration of the
preceding reinforcement. Data are
from the test sessions for each subject.
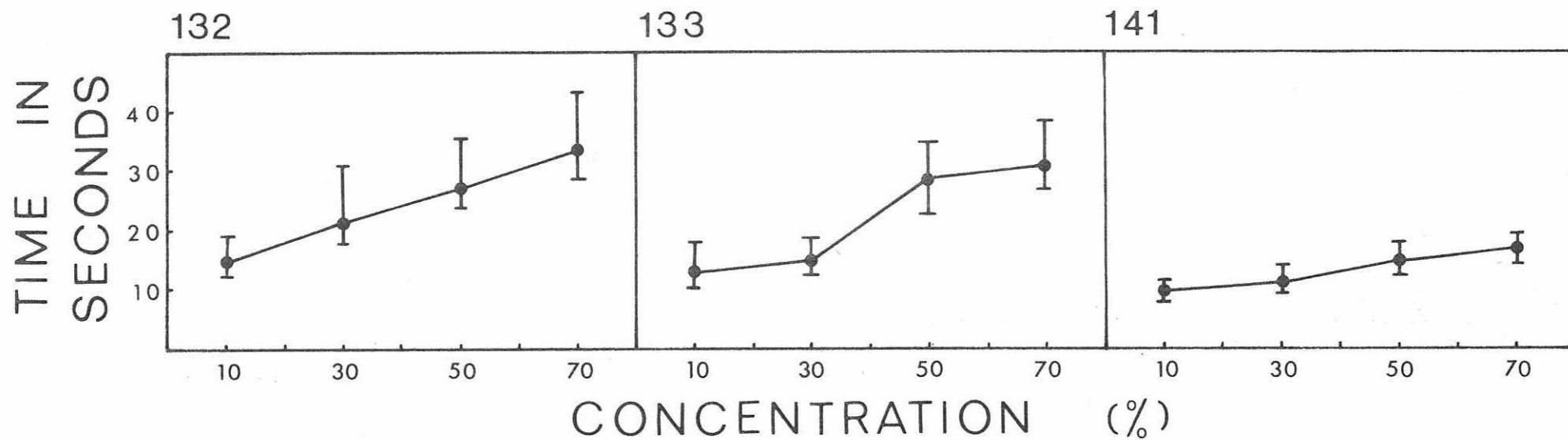
TABLE 11

Mean duration of the postreinforcement pause as a
function of the ordinal position in a block. Data
are from the test sessions.

		ORDINAL POSITION					
CONCENTRATION	ANIMAL	1	2	3	4	5	6
10%	132	16.4	13.3	17.1	14.0	17.7	26.6
	133	13.6	12.0	19.0	14.8	15.2	14.5
	141	8.9	9.4	9.7	9.9	10.9	10.8
	MEAN	13.0	11.6	15.3	12.9	14.6	17.3
30%	132	22.9	21.6	23.5	26.6	22.0	35.9
	133	14.6	18.7	27.4	20.3	27.6	22.0
	141	12.3	10.1	11.5	11.6	15.4	12.8
	MEAN	16.6	16.8	20.8	19.5	21.7	23.6
50%	132	36.6	32.3	32.5	28.4	23.3	46.1
	133	28.1	34.9	31.0	33.1	28.1	28.6
	141	16.9	14.0	14.4	15.3	14.7	13.2
	MEAN	27.2	27.1	26.0	25.6	22.0	29.3
70%	132	44.5	35.8	37.8	35.2	41.5	27.6
	133	43.9	30.1	39.1	28.8	34.1	37.9
	141	18.7	17.3	15.1	17.7	15.4	16.4
	MEAN	35.7	27.7	30.7	27.2	30.3	27.3

The mean running rates showed considerable variation (Figure 48). There was some tendency for rate to decline with higher concentrations. This is also seen in the median and interquartile range of running rates shown in Figure 50.

Overall response rate on the FR schedules clearly declined as a function of magnitude of reinforcement (Figure 48).

Discussion

On the FR schedule, as well as on tand FR 1 FI 60, the behavioural effects of increasing the concentration of the reinforcer, i.e., the longer post-reinforcement pauses and the lower overall response rates, resulted in a lower rate of reinforcement. The present results thus confirm the finding of Experiment 8, that increasing the magnitude of reinforcement enhances the inhibitory after-effects of the reinforcing stimulus.

The inverse relation found in the present experiment between overall response rate and reinforcement magnitude is consistent with the results of Hurwitz et al. (1965) who reported that rats responded at a lower overall rate on an FR schedule when reinforced by a 32%

Figure 50. FR: the median and interquartile range of the running rates in each inter-reinforcement interval as a function of concentration of the preceding reinforcement. Data are from the test sessions for each subject.
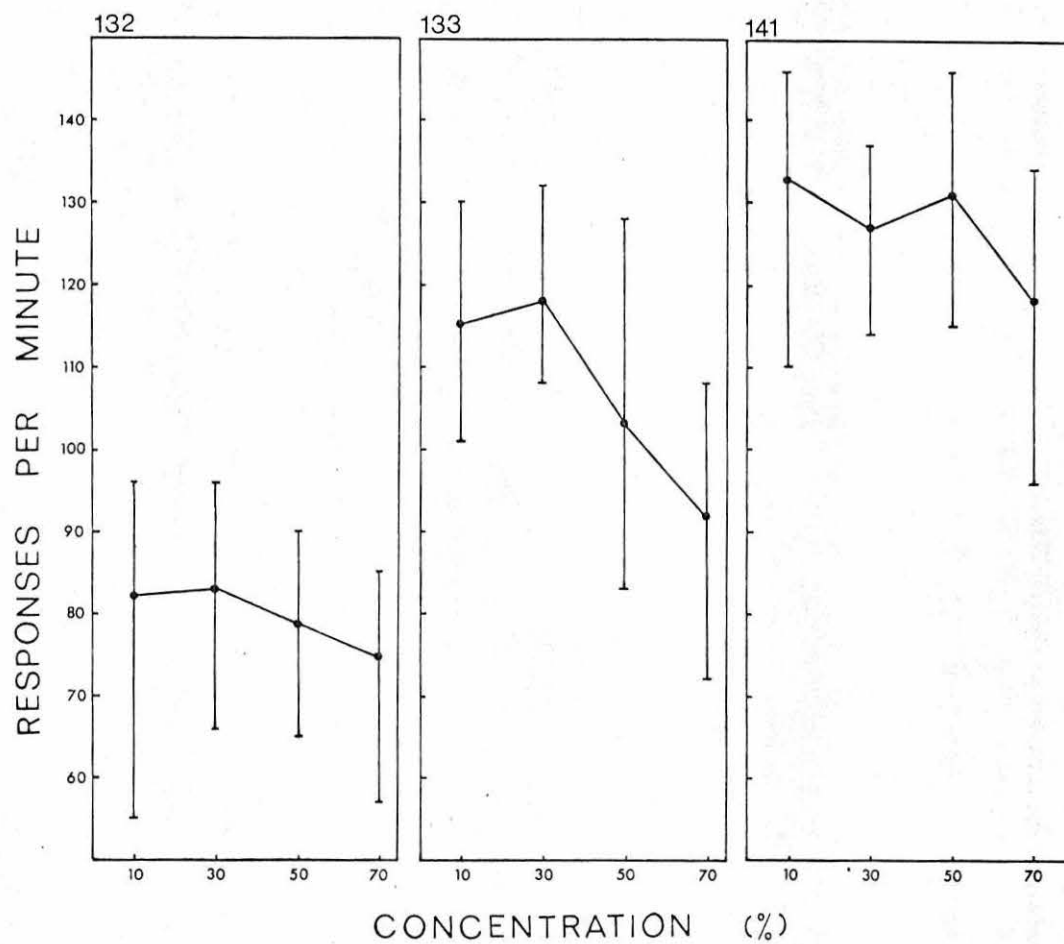
sucrose solution than when reinforced by an 8% solution; they did not record the duration of the post-reinforcement pauses or the running rate. A similar relationship between overall rate and high concentrations of a saccharin solution has been recorded by Weinstock et al. (1965).

The data reported by Bitgood and Platt (1973) show some tendency for the post-reinforcement pauses of pigeons, responding on FR 60 for different durations of grain reinforcement, to increase as a function of reinforcement duration. These results are in agreement with those of the present study. However, Powell (1969) found that the post-reinforcement pause on FR was inversely related to reinforcement magnitude. He presented two different durations of the reinforcer, each in the presence of a different stimulus; the control by the accompanying stimuli may have overridden the inhibitory effects of longer durations of reinforcement. Powell's results differ as well from Staddon's (1970 a) finding, also with duration of reinforcer but on an FI schedule, that the post-reinforcement pause increased as a function of the duration of the preceding reinforcement.

GENERAL RESULTS

It was argued in Chapter 6 that the reinforcement
contingency on the t_1 component of DRL schedules sets
an upper limit on the duration of IRTs which occur on t_1,
i.e., the post-reinforcement pauses. The lower limit,
it was suggested, was determined by the delay of
reinforcement contingent upon a non-reinforced response.

The combination of both of these factors was
probably responsible for the close control of the
duration of the post-reinforcement pause when the
concentration of the reinforcer was varied on the DRL
schedules in Experiment 6;   though the duration of t_1
IRTs increased as a function of concentration, the range
of effect over the different concentrations was relatively
small (approximately 2 sec for the median IRTs).

Similar control of responding does not exist
in the other three schedules studied in this chapter:
FI, tand FR 1 FI, and FR. On these schedules, it has
been suggested, the reinforcer controls a pause after
reinforcement, the duration of which is determined by the
period of non-reinforcement that the reinforcer signals.
The post-reinforcement pause on these schedules should thus
bear a consistent relation to the inter-reinforcement
interval (cf. Chapters 2 and 6). This analysis is supported
by the present results.

In Figure 51 (left panel) the mean post-reinforcement pause duration is shown as a function of the reinforcer concentration, on the three schedules: FI, tand FR 1 FI, and FR. The results were different in the three experiments in terms both of the duration of the post-reinforcement pauses and of the rates at which each function changed. The functions of the FI and FR schedules were approximately linear while that for tand FR 1 FI was positively accelerated. When, however, the proportional post-reinforcement pause, that is, the duration of the post-reinforcement pause relative to the duration of the inter-reinforcement interval, was considered (right panel), the shapes of the functions did not differ greatly; these were approximately linear in all three schedules.

The running rate data from Experiment 7 show that when the magnitude of reinforcement was increased on the FI schedules the running rate also increased accordingly. Some running rate increases, as a function of concentration, were also present on the tand FR 1 FI schedules. These results would appear to be in agreement with those studies which have reported a rate-enhancing effect of reinforcement magnitude on performance (e.g., Crespi, 1942; Zeaman, 1949;

Figure 51. Post-reinforcement pause
(left panel), and post-reinforcement
pause proportional to the inter-
reinforcement interval (right panel),
as functions of reinforcement
concentration. Data were averaged
across the test sessions for the three
rats, on each schedule.
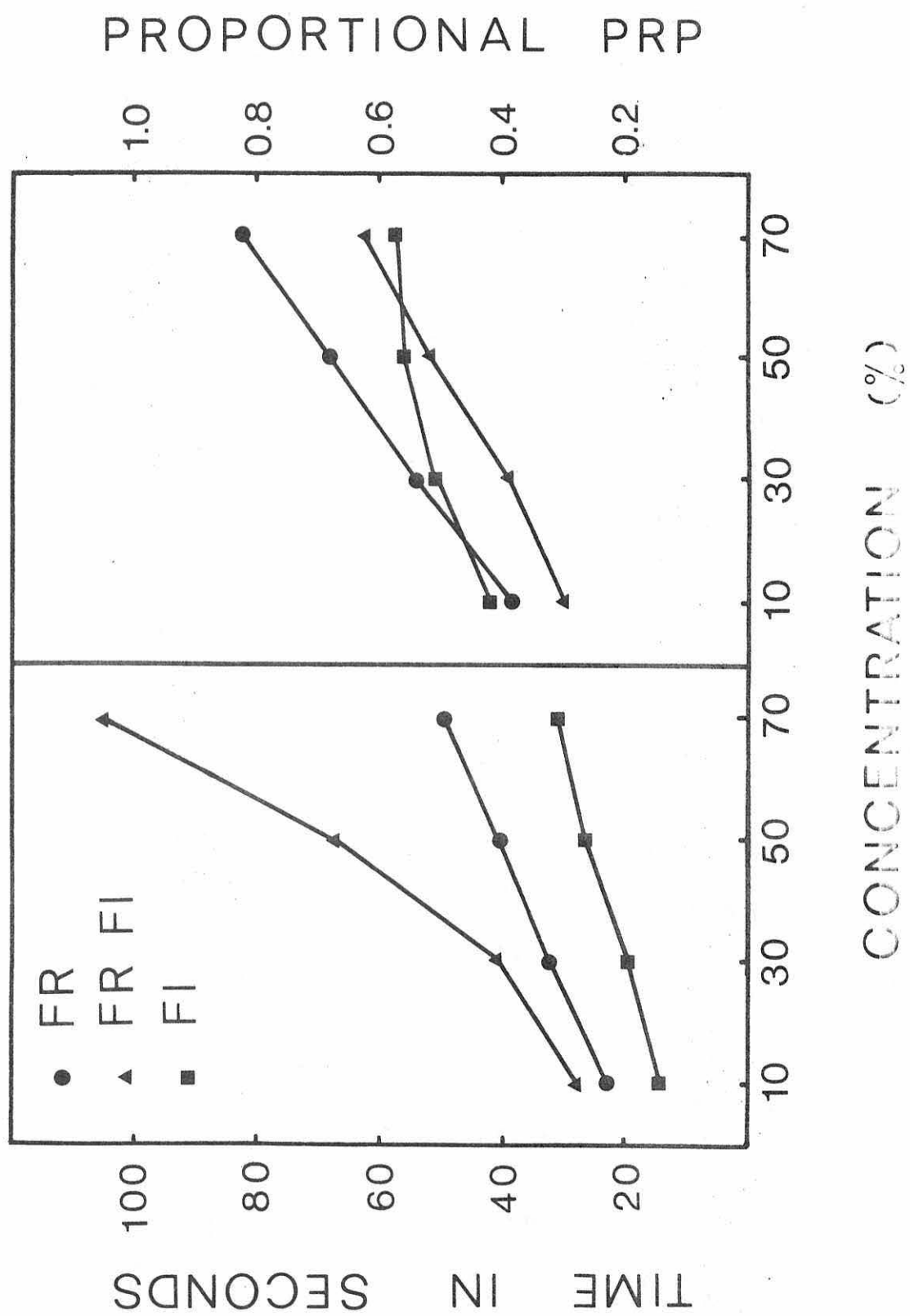
Guttman, 1953), attributed by many theorists to
motivational effects of the reinforcer (cf. Bartoshuk,
1971).

This explanation however, does not account for
the absence of any increase in running rate on the FR
schedules as a function of concentration. Neither does
it explain the more substantial running rate effects on
the FI schedule than on tand FR 1 FI. One possibility
is that the changes in running rate were not determined
directly by changes in the reinforcer, but by the longer
post-reinforcement pauses which followed higher concentrations.

On standard FI, tand FR 1 FI, and FR schedules, the
post-reinforcement pause tends to vary from one inter-
reinforcement interval to another; running rates within
these intervals also vary. The left panel of Figure 52
shows the mean running rates as a function of the duration
of the preceding post-reinforcement pause, in the final
three days of training on FI, tand FR 1 FI, and FR
(i.e., at 30% concentration). (The FR data were taken only
from Animals 132 and 133; due to an oversight the running
rate was not recorded for Animal 141 during the training
sessions). The running rate was found to be an increasing
function of the duration of the preceding post-reinforcement

Figure 52. Running rate as a
function of duration of the preceding
post-reinforcement pause averaged
over the last three training sessions
(left panel), and averaged over testing
sessions (centre panel), across the
three rats on each schedule. Right
panel shows the running rate as a
function of concentration of the
preceding reinforcement; data were
averaged over test sessions, across the
three rats on each schedule.
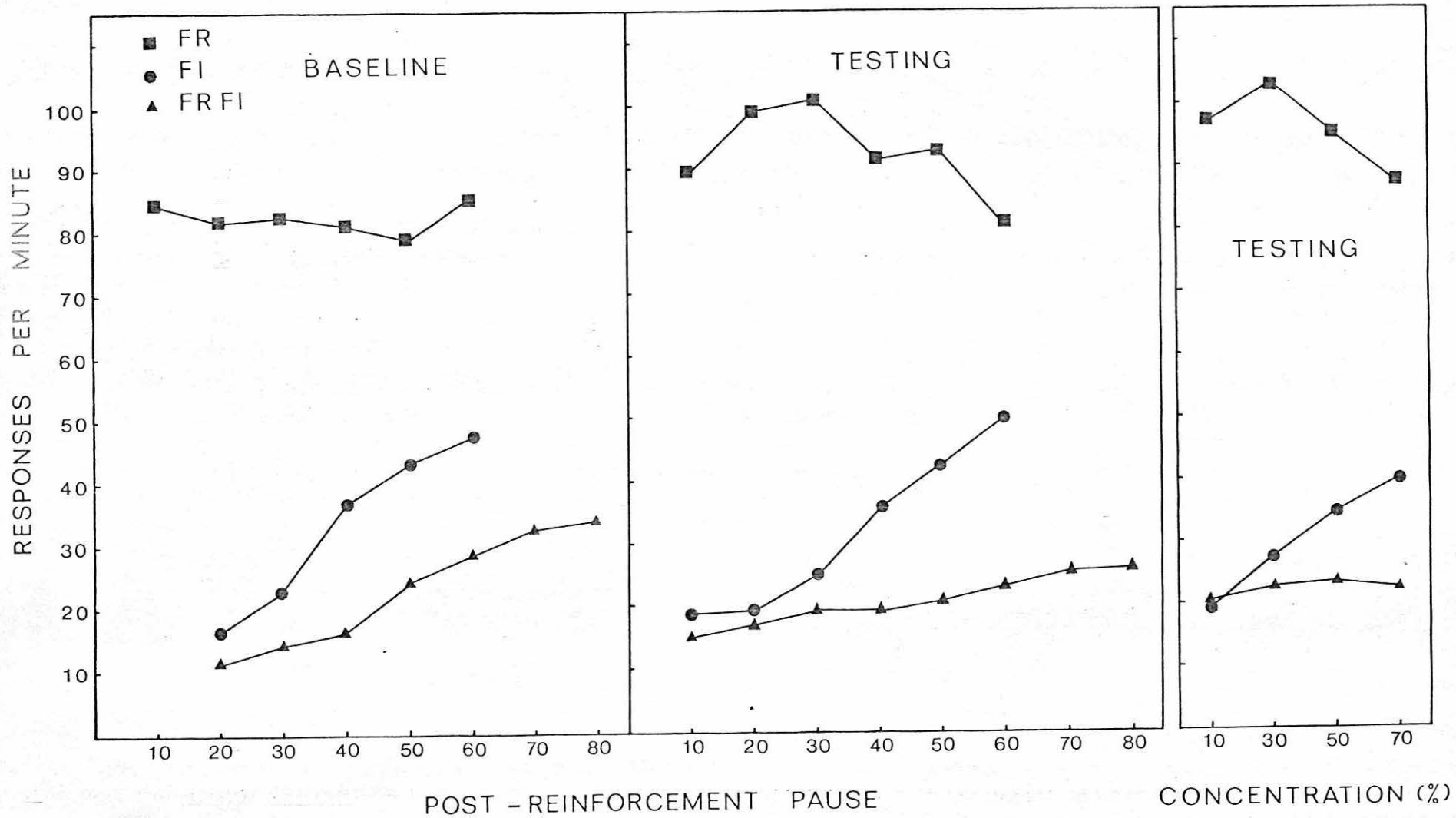
pause on the FI schedule and also, to a lesser extent, on the tand FR 1 FI schedule; the function for the FR schedule was flat. Similar relationships were also found between the running rate and the duration of the preceding post-reinforcement pause in the test sessions, regardless of concentration (see centre panel of Figure 52). The right panel of Figure 52 shows mean running rate during testing on each schedule as a function of the concentration.

In the case of the two interval schedules, the running rates increased as a function of the concentration of the preceding reinforcer. Although this might be explained with reference to an energising effect of reinforcement, enhanced when the concentration was increased, it seems more likely that the increases in the running rate were a consequence of longer post-reinforcement pauses produced, in turn, by higher reinforcer concentrations. The latter suggestion is strongly supported by the mean running rate functions for the two interval schedules. These indicate that the response rate in any one interval is related to the temporal point in that interval when responding commences; the longer the pause, the further the point of time in the interval and the higher the subsequent response rate. This evidence

suggests that the determinants of the response rate
are temporal, rather than motivational, factors.

Though the direct relationship between running
rate and absolute duration of the post-reinforcement
pause is stronger in the FI than in the tand FR 1 FI
schedule, when the running rates on both these schedules
are plotted as a function of the proportional post-
reinforcement pause (Figure 53), the curves are very
similar. This suggests that, for interval schedules,
it is the time which has elapsed since the preceding
reinforcement relative to the inter-reinforcement interval
which determines the rate of responding.

GENERAL DISCUSSION

Stebbins et al. (1959) noted that rats on an
FI schedule responded at a lower rate early in the
fixed interval when a high concentration of sucrose
solution was used as a reinforcer. They suggested that
this reflected an improvement in the temporal patterning
of responding produced by increased reinforcement
magnitude. Low overall response rates were also reported
by Walker (1969) for rats responding for high sucrose
concentrations on an FI schedule. Walker endorsed the
suggestion of Stebbins et al. that greater magnitude of

Figure 53. Running rate is shown
as a function of duration of the
preceding post-reinforcement pause
proportional to inter-reinforcement
interval. Data were averaged over
the last three training sessions
across the three rats on the tand
FR 1 FI (solid line) and FI (broken
line) schedules. The data points
are from individual animals.
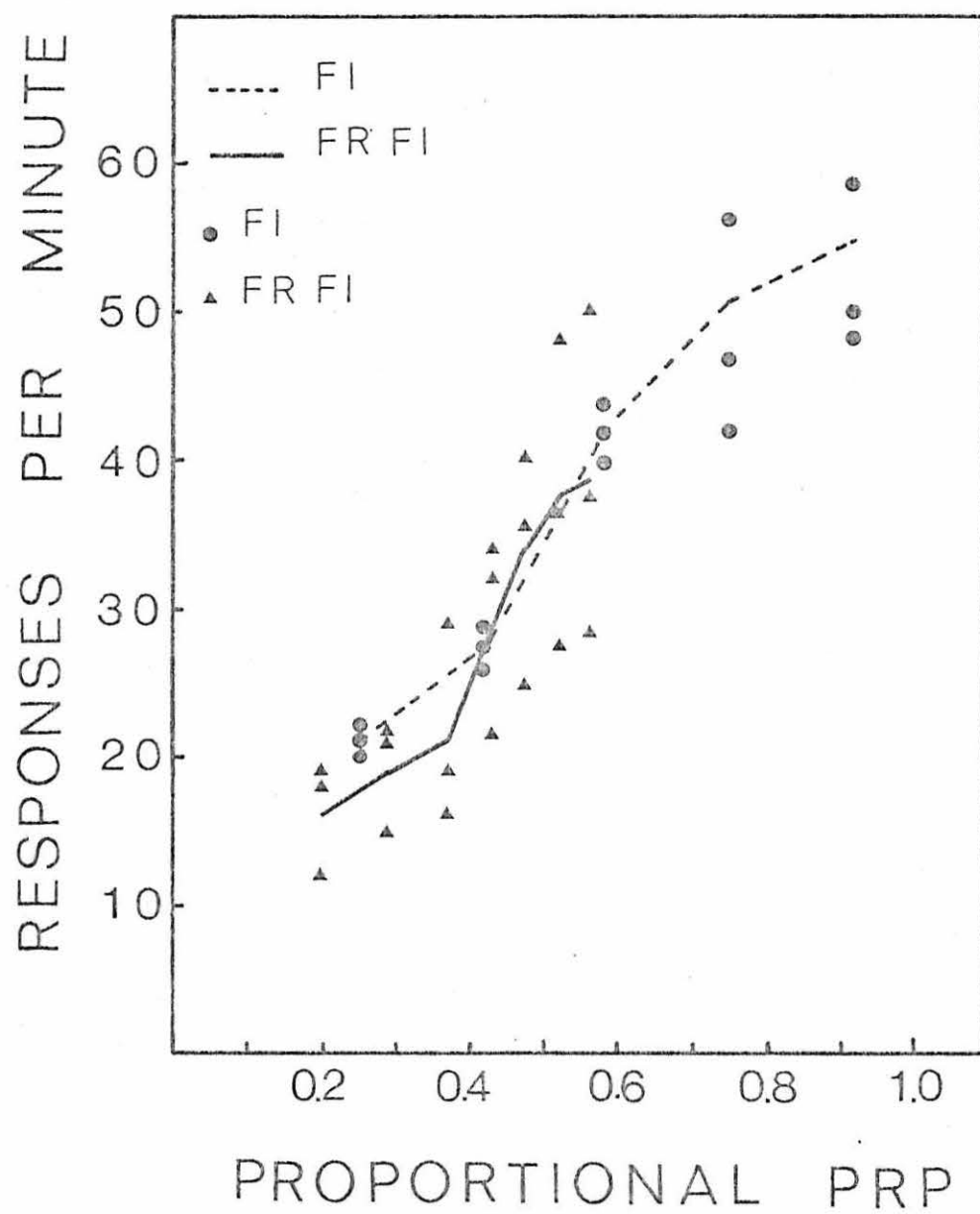
reinforcement reduces response rate on FI by enhancing discrimination of the temporal contingencies.

Similar conclusions have been reached by Di Lollo et al. (1965) and Notterman and Mintz (1965), who reported that when a response force criterion was used on a CRF schedule, the force and variability of responses varied inversely as a function of reinforcement magnitude; response force on the higher magnitudes approximated the criterion better than did responses which produced smaller amounts of the reinforcer. To account for these findings, they put forward the explanation that increasing the magnitude of the reinforcer enhances its discriminative effect, so that there is a general improvement in the precision of performance. This hypothesis would appear to be in agreement with other results which have shown a positive relationship between reinforcement magnitude and effective discrimination in the T maze (Reynolds, 1950; Smith and Duffy, 1957) and in runway situations (Waller, 1968; Weisinger, Parker and Bolles, 1973).

The finding that increasing the magnitude of the reinforcer results in (i) a longer post-reinforcement pause on an FI schedule (Staddon, 1970 a), (ii) an increase in the index of curvature in the fixed interval

(Jensen and Fallon, 1973), and (iii) a lower response rate early in the fixed interval (Meltzer and Howerton, 1973), are also consistent with the notion that increasing reinforcement magnitude improves the precision of performance. In these studies when the magnitude of the reinforcer was increased the subjects made fewer responses early in the fixed interval when reinforcement was never available, but maintained the same rate of reinforcement.

The present experiments, however, have shown a direct relationship between the magnitude of the reinforcer and the duration of the following post-reinforcement pause on schedules in which longer post-reinforcement pauses (a) resulted in higher rates of reinforcement, i.e., DRL schedules, (b) had no effect on reinforcement rate, i.e., FI schedules, and (c) produced a reduction in reinforcement rate, i.e., tand FR 1 FI and FR schedules. These results cannot be explained in terms of an enhanced accuracy of performance related to reinforcement magnitude. They do on the other hand, clearly suggest that the reinforcer on these schedules has inhibitory properties which are enhanced when the magnitude of reinforcement is increased.

The inhibition hypothesis also accounts for the findings of those studies which have reported depressive after-effects of reinforcement magnitude on FI schedules (Stebbins et al., 1959; Staddon, 1970 a; Jensen and Fallon, 1973; Meltzer and Howerton, 1973). The inverse relation between response force and reinforcement magnitude reported by Di Lollo et al. (1965) and Notterman and Mintz (1965) may also be due to inhibitory effects of the reinforcer rather than to a direct effect of the reinforcer on precision of performance.

The present results are thus in agreement with the evidence presented in Chapter 3, which suggested that the reinforcer on DRL schedules has inhibitory after-effects. These results also support the notion that the longer IRTs which occur after reinforcement on DRL, as compared with IRTs which follow non-reinforced responses, are due to the greater intensity of stimulation at reinforcement.

It was indicated in Chapter 2 that the post-reinforcement pause on both FI and FR schedules was a function of similar temporal variables (cf. Neuringer and Schneider, 1968; Killeen, 1969; Staddon, 1972). It was argued that when the reinforcer signals a period of non-

reinforcement, i.e., the inter-reinforcement interval,
it develops temporal inhibitory properties which are
proportional to the duration of that interval. The
similarity of the proportional post-reinforcement pause/
concentration functions on FI, FR, and tand FR 1 FI, in
the present study (Figure 51), lends support to this
account and indicates that the inter-reinforcement
interval was the factor common to all these schedules
in determining the relation between the magnitude of
the reinforcer and the duration of the post-reinforcement
pause.

The present study has been concerned with the
after-effects of the reinforcer on schedules of
reinforcement, but the results obtained are also in
general agreement with the findings in runway studies
that presentation of food, in the start box (Seward,
Pereboom, Butler and Jones, 1957; McCain and Power,
1966; Kemble and Clayton, 1967), or in the first
goalbox of a double runway (Bower, 1962; McHose and
Ludvigson, 1965; Daly, 1968; Karabenick, 1969),
depresses the subsequent running speed — an effect
which is enhanced by increases in the amount of food.
Whether these depressive after-effects of reinforcement
on runway performance are a function of temporal variables

similar to those which operate on schedules of
reinforcement has yet to be established.

Running rate

On the FI schedule and to a lesser extent on
tand FR 1 FI, the running rate increased when it
was preceded by an increase in both the concentration
of the reinforcer and the duration of the post-
reinforcement pause. The question of which of the
latter changes affected the running rate directly,
is answered partly by the finding that when, during
training on the FI and tand FR 1 FI schedules, the
reinforcer concentration was held constant, the running
rate was nevertheless an increasing function of the
length of the preceding post-reinforcement pause. This
suggests that the running rate is affected directly by
the duration of the post-reinforcement pause, but that
the effect of the concentration of the preceding
reinforcer is indirect, mediated through the post-
reinforcement pause.

If this is so, it would be expected that in those
cases where the running rate is not positively related
to the preceding post-reinforcement pause duration, a
positive relationship with the preceding reinforcement

magnitude should be also absent. There is some evidence
to confirm this. Figure 54 presents data from three
pigeons, following 30-40 sessions exposure to an FI
60-sec schedule; the data were taken from 3 consecutive
sessions.* This shows, contrary to the functions
obtained from rat subjects, that running rate did not
increase as a function of the preceding post-reinforcement
pause duration. There was some tendency in the rates of
two of the birds, 1A and 6A, to decline following the
longer post-reinforcement pauses. Staddon (1970 a), who
found longer pauses following increased reinforcement
magnitude on an FI 60-sec schedule with pigeons, reported
that running rate declined as a function of the magnitude
of the preceding reinforcer.

This evidence indicates that, on FI schedules, the
relationship between running rate and the duration of
the preceding post-reinforcement pause is very different
in the case of rats and pigeons. It appears that for
either species the effects of reinforcement magnitude on
running rate is determined primarily by the effect of
changes in the reinforcer on the duration of the post-
reinforcement pause.

* I am grateful to Graham Davey for the data
presented in Figure 54.

Figure 54. Mean running rate (responses
per minute) as a function of the duration
of the preceding post-reinforcement
pause (sec) for three pigeons, responding
on an FI 60-sec schedule of reinforcement.
The data were averaged over three
consecutive sessions.
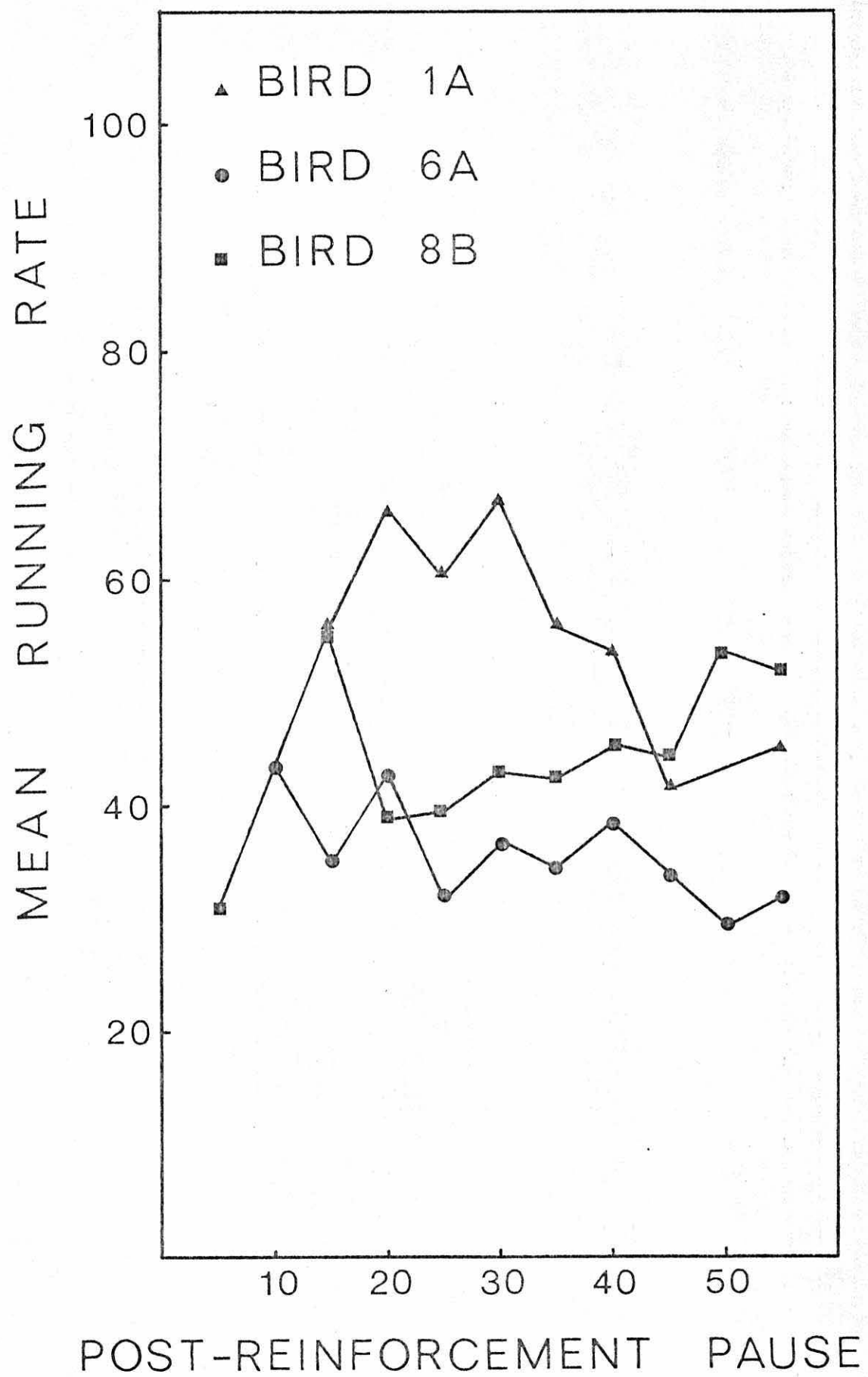
These results have considerable implications for explanations of performance on FI schedules. A number of studies have been concerned with determining the factors which control the post-reinforcement pause and the running rate on FI. Farmer and Schoenfeld (1964 b), for example, added an IRT requirement to responses on an FI schedule which had the effect of lowering the running rate but the duration of the post-reinforcement pause remained unaffected. Other investigators (Neuringer and Schneider, 1969; Killeen, 1969; Shull, 1970 b; Shull et al. ,1972) have altered the response-reinforcement contingency on FI schedules in various ways with similar results. On the basis of such evidence it has been concluded that the post-reinforcement pause and the running rate are independently determined; the former is a function of the inter-reinforcement interval while the latter is determined by the rate of responding prevailing at the moment of reinforcement (Schneider, 1969; Shull, 1970 b; Shull et al., 1972).

Though they have shown that when running rate is altered there is no effect on the post-reinforcement pause, none of these studies has attempted to investigate the effect of changes in the post-reinforcement pause upon

response rate. The present findings show, at least
for rats, a strong positive relationship on FI
schedules between running rate and the duration of the
preceding post-reinforcement pause; this clearly
demonstrates that both are not independent. The
subject's relative position in the inter-reinforcement
interval would appear to determine not only whether the
pause after reinforcement will be terminated by a
response (Sherman, 1959; Dews, 1970), but also the
rate of responding, once responding has commenced
(Figure 53).

The greater sensitivity of rats' performance to
these temporal variables, as compared with that of
pigeons, may be related to differences in performance
on the DRL schedule, discussed in Chapter 3. For
example, pigeons' performance on DRL, when the operant
is a pecking response, is much less efficient than that
of rats (Holz et al., 1963; Staddon, 1965; Richardson
and Loughead, 1974 b). It has also been reported,
however, (i) that whilst pigeons can readily discriminate
time intervals, they are unable to withhold pecking
until a time when reinforcement is available (Reynolds,
1966), and (ii) that pigeons' performance on a DRL
schedule becomes more like that of rats when the response

studied is stepping on a treadle (Hemmes, 1970).
These findings suggest that the differences observed
in the post-reinforcement pause/running rate functions
of rats and pigeons may reflect phylogenetic "constraints"
on behaviour at a peripheral-response level (cf. Hinde
and Stevenson-Hinde, 1973).

Overall rate

If in the present case the overall rate were the
only measure of behaviour, several aspects of the
behavioural effects of reinforcement magnitude would
have been overlooked. For example, on the FI schedule
studied, reinforcement concentration had almost no
effect on the overall rates of two out of three animals,
whereas both the post-reinforcement pause and the
running rate changed considerably.

In many previous experiments the magnitude of
reinforcement was manipulated during acquisition, before
the establishment of stable performance (Guttman, 1953;
Hutt, 1954; Collier and Siskel, 1959; Collier and
Myers, 1961; Collier and Willis, 1961; Collier, 1962).
In these studies increases were reported in the overall
rates of responding as a function of reinforcement
magnitude. The present results, obtained after exposure

to the schedules for 40-50 sessions, extend but do not contradict the earlier findings, since the inhibitory after-effects of reinforcement develop as behaviour stabilises on a given schedule (cf. Ferster and Skinner, 1957; Gott and Weiss, 1972).

The present evidence suggests that where no effect or a decline in overall response rate has been observed as a function of reinforcement magnitude (Keesey and Kling, 1961; Hurwitz et al., 1965; Walker, 1969) longer post-reinforcement pauses may have been responsible for depressing the response rate. The rate of responding, once the animal begins to respond in an interval, i.e., the running rate, may show no effect of reinforcement magnitude or may even increase. But this may not be reflected in the overall rate measure.

These findings may have implications for the application of reinforcement principles to the modification of human behaviour. If an increase in a subject's response rate or vigour is required, then increasing the magnitude of reinforcement may have the opposite effect to that which is desired since response rate may decline as a function of

reinforcement magnitude due to an enhanced inhibitory effect of the reinforcer.

Though little research has been conducted on the parametric effects of reinforcement schedules with human subjects (Schroeder, 1972), there exist two studies on the effects of reinforcement magnitude with retardate subjects,which have provided data consistent with this suggestion. Ellis (1962) found that when the amount of reinforcement, cigarettes or candy, was varied on an FR schedule, overall response rate was inversely related to the magnitude of the reinforcer. Similar findings have been reported in a study by Schroeder (1972) who studied the work rate of retardate employees in a Sheltered Workshop. Each use of a workshop tool was recorded as a response and reinforced on FI, FR, VI, or VR schedules; 1-, 5-, and 10- cent tokens were used as reinforcers. It was found that increasing the value of the tokens resulted in a decline in response rate and, consequently, in the output of components manufactured in the workshop.

The authors of both these studies found the inverse relationship between a human's response rates and the magnitude of reinforcement difficult to explain in terms of existing reinforcement principles. Although only

overall rates of responding were recorded, it seems

likely, as in the animal experiments of the present

thesis, that the decline in response rate may have

been due to longer pauses following the greater

reinforcement magnitudes. The evidence presented in

this chapter certainly does suggest that whenever the

magnitude of reinforcement is manipulated it is necessary

that account be taken as much of the inhibitory after-

effects of the reinforcer as of its motivational effect

as a consequence of behaviour.

CHAPTER 9

CONCLUSION

The results of the experiments reported in this
thesis show that both reinforced and non-reinforced
responses play an important part, as antecedent
stimulus events, in the temporal patterning of responses.
Their particular effects on subsequent responding may
be described as follows:

1. In two-component DRL schedules both events
function as distinct discriminative stimuli, each
controlling IRTs appropriate to the DRL contingency
in operation.

2. In addition, there are unconditioned
differences in the stimulation provided by reinforced

and non-reinforced responses. In DRL schedules,
where the t_1 and t_2 components are of equal duration,
IRTs are longer after reinforcement than after non-
reinforced responses. Moreover, the post-reinforcement
pause/concentration functions obtained on each of the
schedules studied, indicate that there is an
interaction between the intensity of the reinforcing
stimulus and the inhibitory effect of the reinforcer.

3. In DRL schedules non-reinforced responses,
apart from having discriminative properties, also
produce emotional or frustrative after-effects
resulting in bursts of responding.

These findings have implications for traditional
explanations of the "frustration effect" (Amsel,
1958). If "reward" is occasionally omitted in the
mid-goalbox of a double runway, rats will run faster
in the second alley on those trials than on trials
when reward is present in the mid-goalbox, (e.g., Amsel
and Roussel, 1952; Wagner, 1959). Comparable effects
have been demonstrated following non-reward in various
operant analogues of the double-runway situation.
These have usually involved the omission of reinforcement
in the first response chain of a double-chain operant;
higher response rates following non-reinforcement have

been reported with a variety of subjects, e.g., monkeys
(Davenport and Thompson, 1965; Davenport et al.,
1966), pigeons (Staddon and Innis, 1966; Hamm and
Zimmerman, 1967), rats (Cole and Van Fleet, 1970;
Platt and Senkowski, 1970; Hughes and Dachowski, 1973).
This increased vigour of responding following non-
reward has been attributed to increased motivation
following omission of an expected reward, i.e.,
"frustrative non-reward" (Amsel, 1958; 1962).

If, however, reinforcement has inhibitory after-
effects then,when the reinforcer is omitted, any
increase in the vigour of responding may be due to
the absence of inhibitory after-effects. Staddon
(1970 b) has suggested that the "frustration effect"
may be explained in these terms and has argued that
the inhibition hypothesis makes explanations in terms
of the energising effects of non-reward redundant.

Much of the evidence in the present thesis supports
the suggestion that the reinforcer has inhibitory
effects in those situations where responding shows a
positive goal gradient (Staddon, 1970 b). But there
is also evidence in support of Amsel's theory. The
frequency of response bursts on the DRL schedules was
found, consistently, to be related to the omission of

expected reinforcement. For example, when
reinforcements were omitted from one component of the
DRL schedules, response bursts at first increased
and then, with chronic non-reinforcement, declined
in frequency, a finding that is directly predicted
by frustration theory. These results, which are
comparable to those obtained in runway studies of
the frustration effect where chronically non-rewarded
control groups have been used (cf. Wagner, 1959; Hughes
and Dachowski, 1973), present difficulties for an
explanation of the effects of reinforcement omission
expressed solely in terms of the absence of inhibitory
effects of the reinforcer.

The present findings suggest that: (i) to the
extent that a reinforcer has inhibitory after-effects,
omission of reinforcement will result in an increase
in the rate of responding, and (ii) the omission of
an expected reinforcer may have, in addition, emotional
or frustrative effects which will actively increase
responding after non-reinforcement. It may be objected
that this formulation, which of course encompasses
both the inhibition and frustration hypotheses is not
parsimonious and as such is a departure from the
"simplicitly postulate" (cf. Woodger, 1952). Nevertheless,

it may be better in this case to be guided by
Beck's (1957) caveat: "...the course of biological
science raises substantial doubts as to the
equivalence of simplicity and validity (p.182)".

It seems important to analyse operant
behaviour in terms of the antecedent stimuli which
maintain temporal control of responses. The measures
of inter-response time and duration of the post-
reinforcement pause used in this study, rather than
a measure of overall rate of responding, appear
especially suitable for analyses of this kind. The
inter-response time and post-reinforcement pause
measures are similar to the measure of response
latency traditionally used in psychology. Latency
has been defined as "an interval of time (which)
elapses between the beginning of the stimulus and the
beginning of the response (Skinner, 1938, p.12)".

In some respects the analysis presented in this
thesis runs counter to traditional conceptions of the
role of response latency in operant conditioning. It
has frequently been maintained that, as operant
behaviour occurs "spontaneously", i.e., not in
response to environmental stimuli, rate of responding,

which serves as an approximation to response
probability, should be the basic datum for a
science of behaviour (Skinner, 1938; 1966).
Skinner (1950) makes the point as follows: "In
recognizing the emissive character of operant
behaviour and the central position of probability
of response as a datum, latency is seen to be
irrelevant to our present task (Pp.198-199)". It
would appear that because the notion of latency
ties the response to an antecedant stimulus, it
finds little place in Skinner's operant analysis.

Little theoretical or empirical justification
has been provided, however, for the assertion that
response rate is the only proper dependent variable
in the study of behaviour. Skinner (1950) has reported
a study of the effects of deprivation level and
extinction on the latency of a key-pecking response
in pigeons. As latencies showed little systematic
relationship to the level of deprivation and showed
considerable variation during extinction, it was
concluded that latencies do not change in a simple
fashion or in a way which matches our preconception
of the learning process. Response rate, it was

claimed, is more sensitive to such variables as motivational changes and in general "appears to be the only datum which varies significantly and in the expected direction under conditions which are relevant to the 'learning process' (p.198)".

The experiments reported here do not support Skinner's argument. For example, though the duration of the post-reinforcement pause was found consistently to be related to the magnitude of the reinforcer, the rate of responding frequently did not show any systematic change. This indicates that the latency measure, i.e., post-reinforcement pause duration, was a more sensitive dependent variable than the rate of responding. Moreover, the sensitivity of the post-reinforcement pause to many of the different schedule parameters which were investigated justifies its use as a dependent variable.

There is another objection made against the latency measure. In discrete-trial procedures where the latency measure has traditionally been used,the subject is often restricted from responding, by means, for example, of the start-box door in runway studies or by the use of a retractable lever in an operant

conditioning chamber. Skinner (1950) has pointed out that the restrictions imposed on behaviour and the complexities involved in these procedures make an assessment of the stimulus-response relationships very difficult. However, as the present study demonstrates, it is possible to use the interval of time which elapses between a stimulus and a response as a dependent variable without imposing restrictions on the free operant.

The inhibitory after-effects of the reinforcer observed in the present study, particularly in the situations where longer post-reinforcement pauses resulted in a decline in the rate of reinforcement, would appear to be inconsistent with a reward maximisation principle (cf. Logan, 1960). Logan and Ferraro (1970), for example, have written:

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

It does seem to be the case that when more than one reinforcement magnitude is available to a subject, as for example on concurrent schedules, responses are

distributed so as to obtain more of the larger reinforcements (see Chapter 7). Such a principle may also govern performance on conventional reinforcement schedules, in which only one reinforcer is available at any one time, but the present evidence suggests that there are limiting conditions. Thus post-reinforcement pauses occur in schedules where the reinforcer signals a period of non-reinforcement even though consequently the density of reinforcement is reduced. Moreover, the greater the magnitude of the reinforcer the greater is the deviation from the maximisation strategy; post-reinforcement pauses are longer, and the rate of reinforcement is lower.

The inhibitory effect of the reinforcing stimulus would thus appear to be an important determinant of performance, at least on the schedules of reinforcement studied in the present thesis. Whether the reinforcing stimulus has similar temporal inhibitory effects on other schedules of reinforcement and in other experimental situations, e.g., in runway studies, remains to be investigated.

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APPENDIX

Figure 55. The overall relative frequency distributions of IRTs for Animal 106 on each schedule. The overall distributions contain all IRTs regardless of the components. Data are from the last two sessions on each schedule.
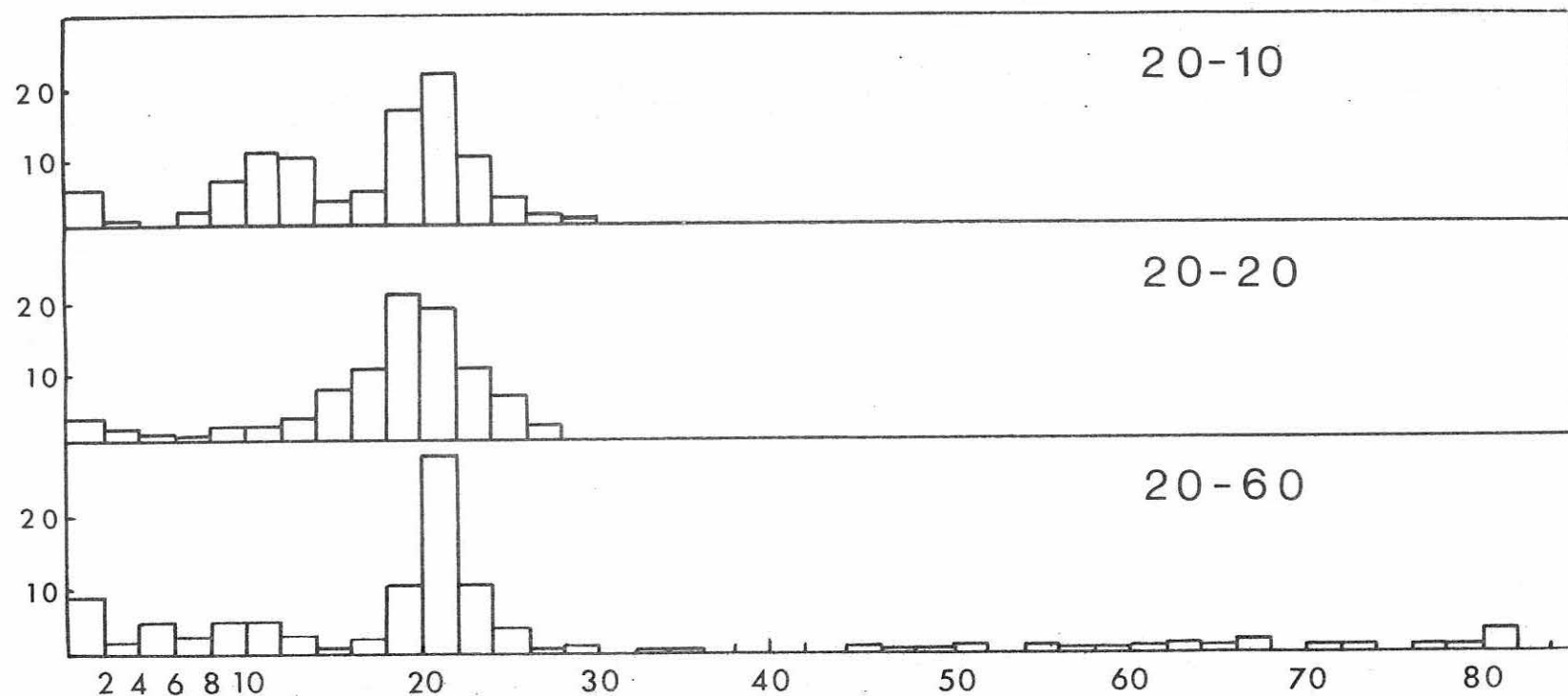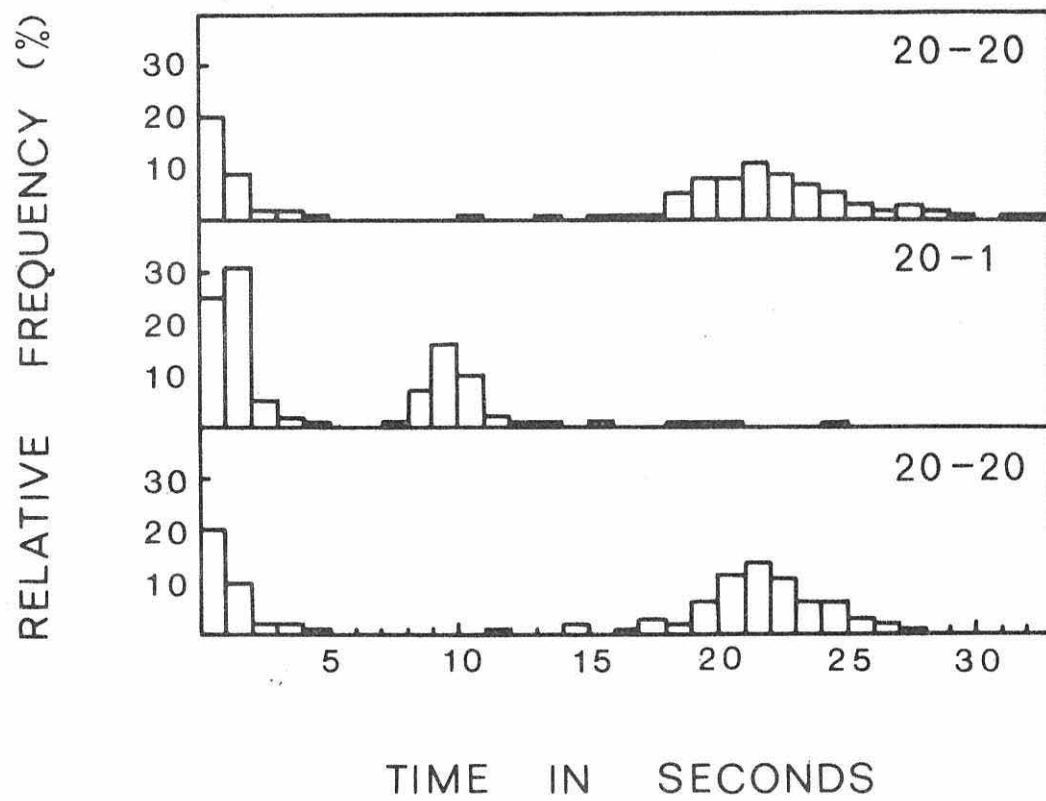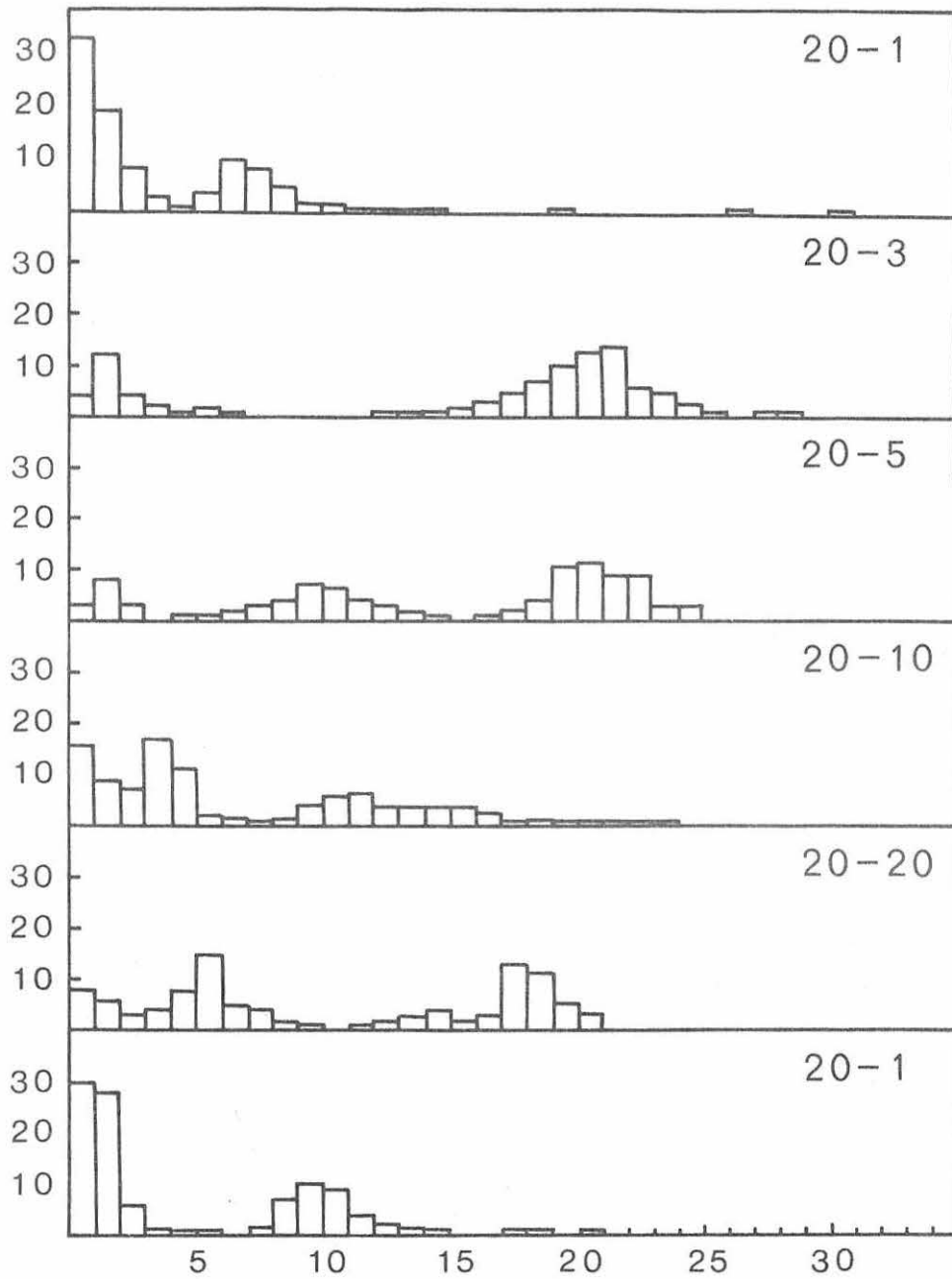
Figure 56. The overall relative
frequency distributions of IRTs
for Animal 107 on each schedule.
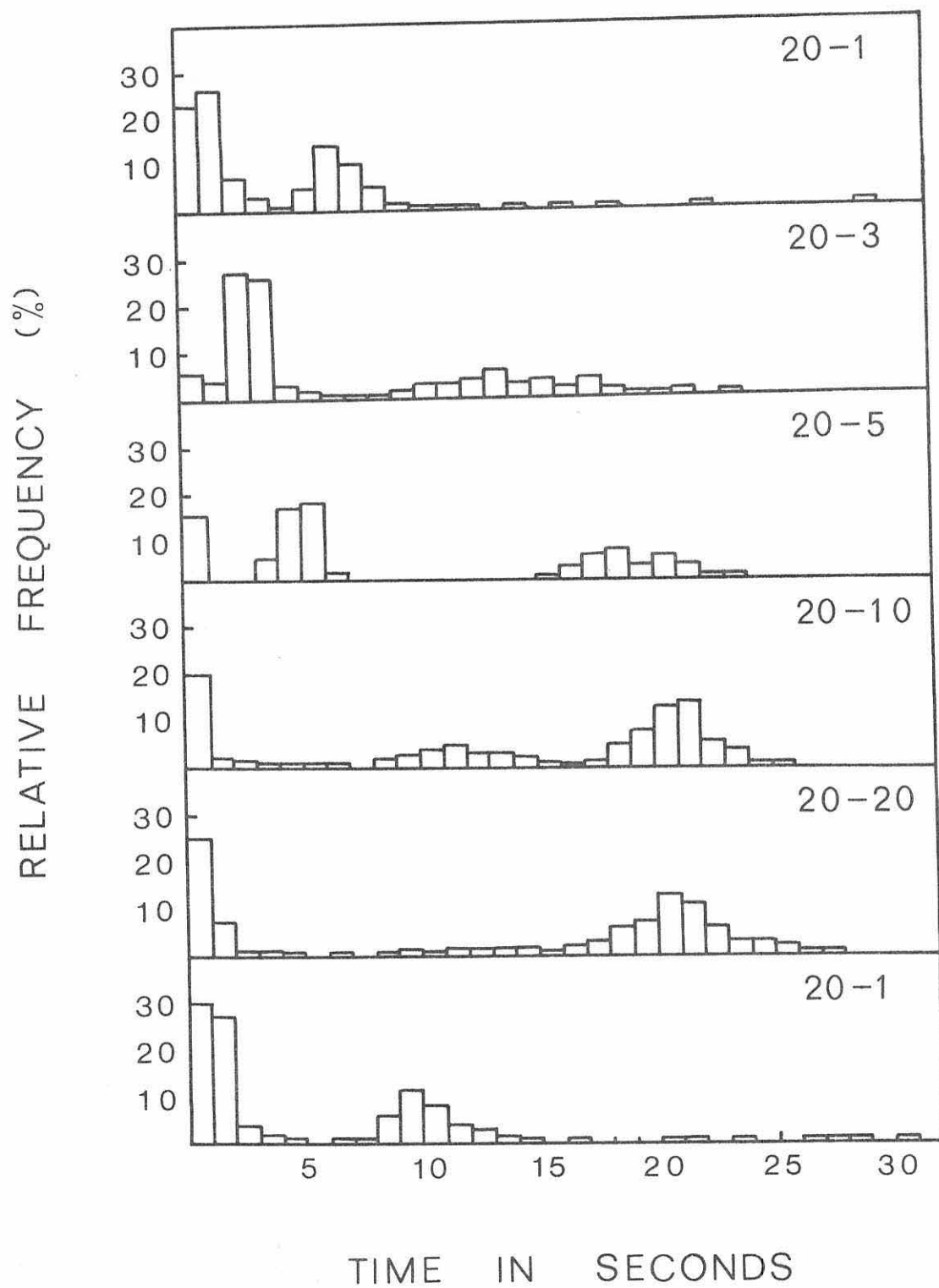Data are from the last two
sessions on each schedule.
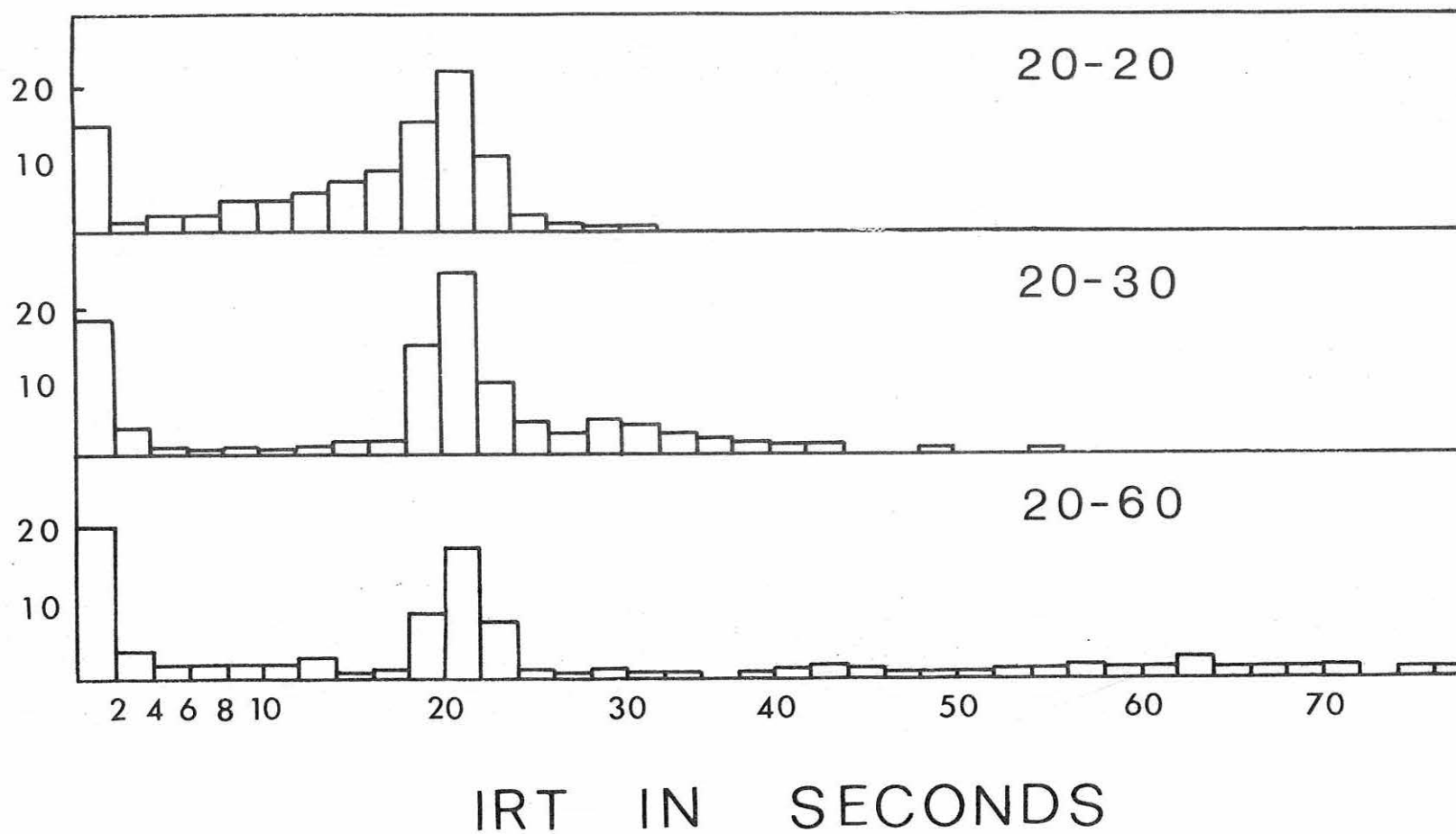
Figure 57. The overall relative
frequency distributions of IRTs
for Animal 103 on each schedule.
Data are from the last two sessions
on each schedule.
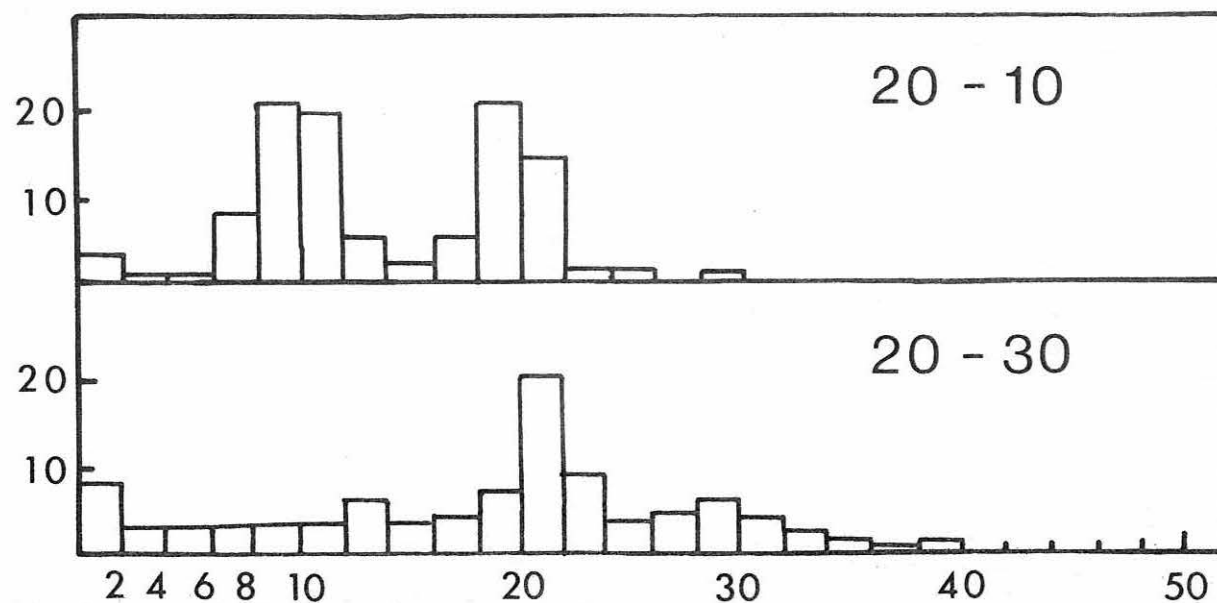
Figure 58. The overall relative
frequency distributions of IRTs
for Animal 105 on each schedule.
Data are from the last two sessions
on each schedule.
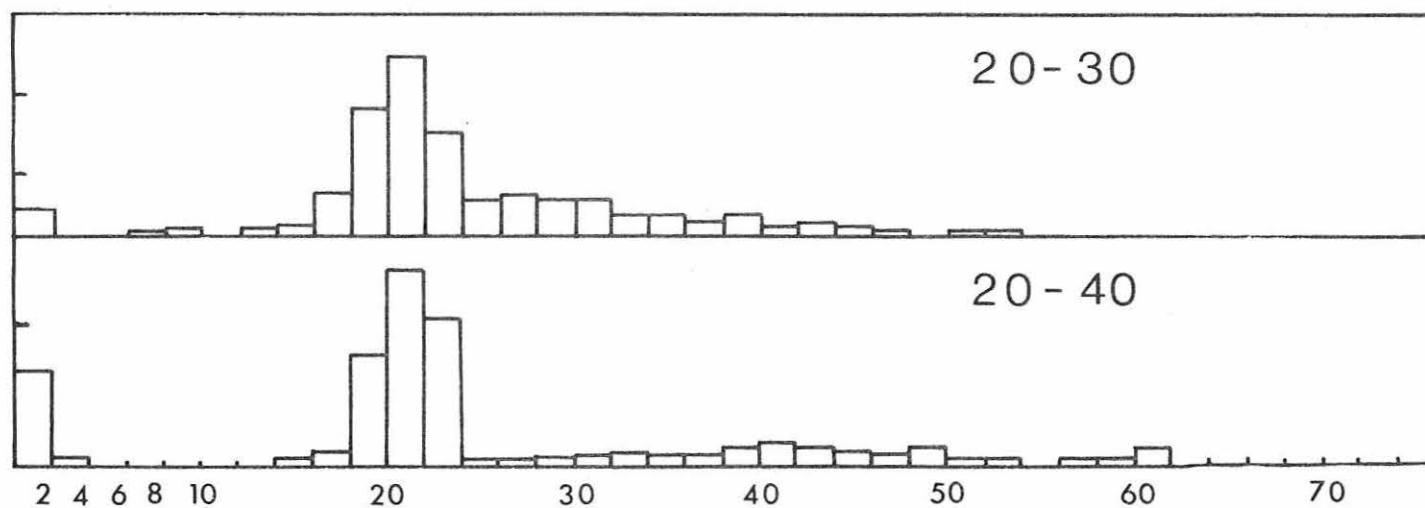
Figure 59. The overall relative frequency distributions of IRTs for Animal 113 on each schedule. The data are from the last two sessions on each schedule.
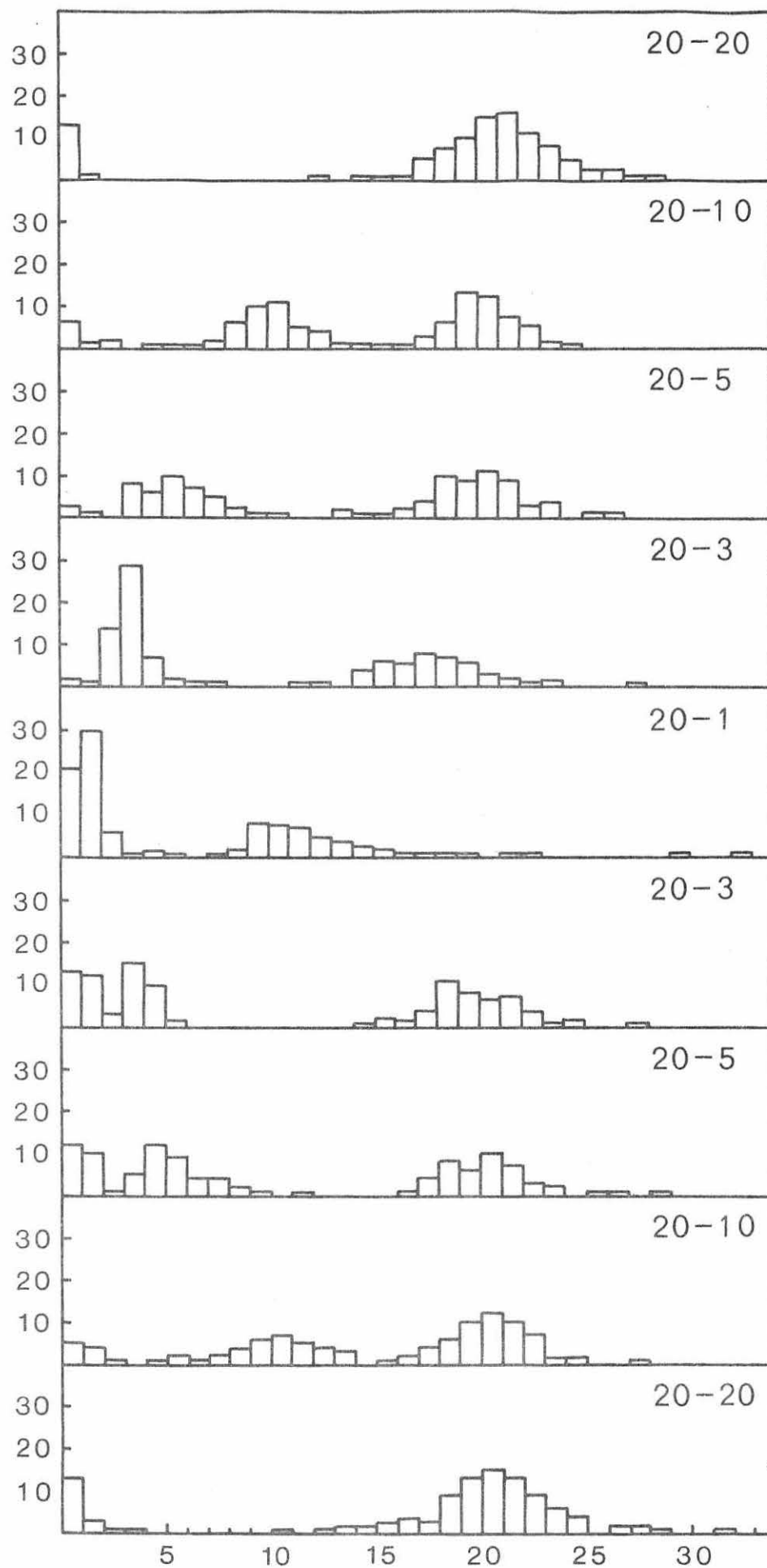
Figure 60. The overall relative
frequency distributions of IRTs
for Animal 143 on each schedule.
The data are from the last two
sessions on each schedule.

Figure 61. The overall relative
frequency distributions of IRTs
for Animal 118 on each schedule.
The data are from the last two
sessions on each schedule.

Figure 62. The overall relative
frequency distributions for Animal
120 on each schedule. The data
are from the last two sessions on
each schedule.

Figure 63. The overall relative
frequency distributions of IRTs
for Animal 101 on each of the four
experimental conditions: (i) DRL
20-10, (ii) DRL 20-10 with a tone
stimulus added to the t_2 component,
(iii) DRL 20-10 with the tone on the
t_1 component, (iv) DRL 20-10 without
the tone stimulus. Data are from the
last two sessions on each condition.

t_2 TONE

t_1 TONE

RELATIVE FREQUENCY — (%)

TIME IN SECONDS
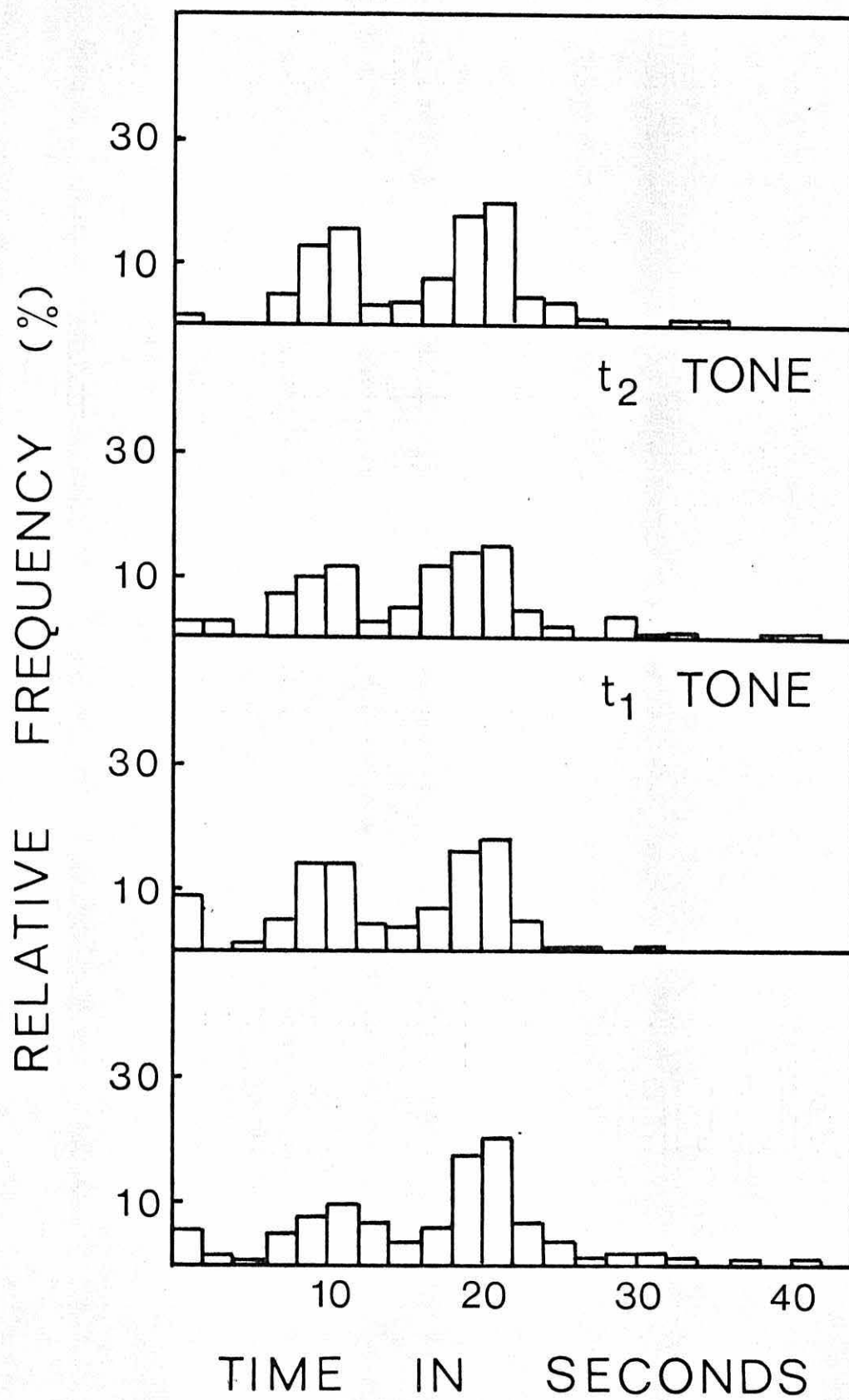
Figure 64. The overall relative
frequency distributions of IRTs
for Animal 104 on each of the four
experimental conditions: (i) DRL
20-40, (ii) DRL 20-40 with a tone
stimulus added to the t_1 component,
(iii) DRL 20-40 with the tone on the
t_2 component, (iv) DRL 20-40 without
the tone stimulus. IRTs longer than
54 sec are contained in the final IRT
category. Data are from the last two
sessions on each condition.
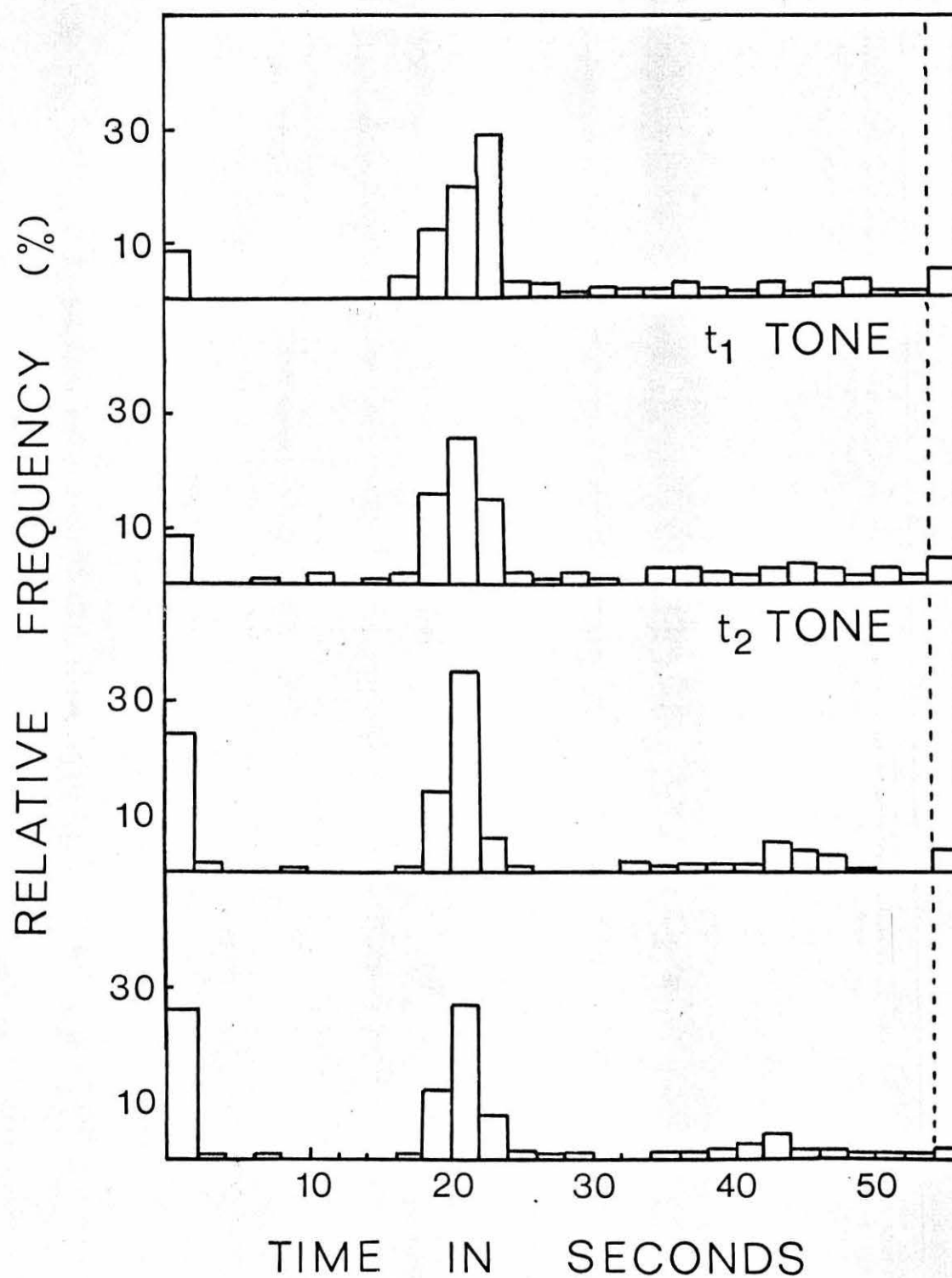
Figure 65. The overall relative
frequency distributions of IRTs for
Animal 101 from (i) the final two
sessions on DRL 20-10 (baseline),
(ii) the first session in which
reinforcement was omitted from the t_2
component (first omission), (iii) the
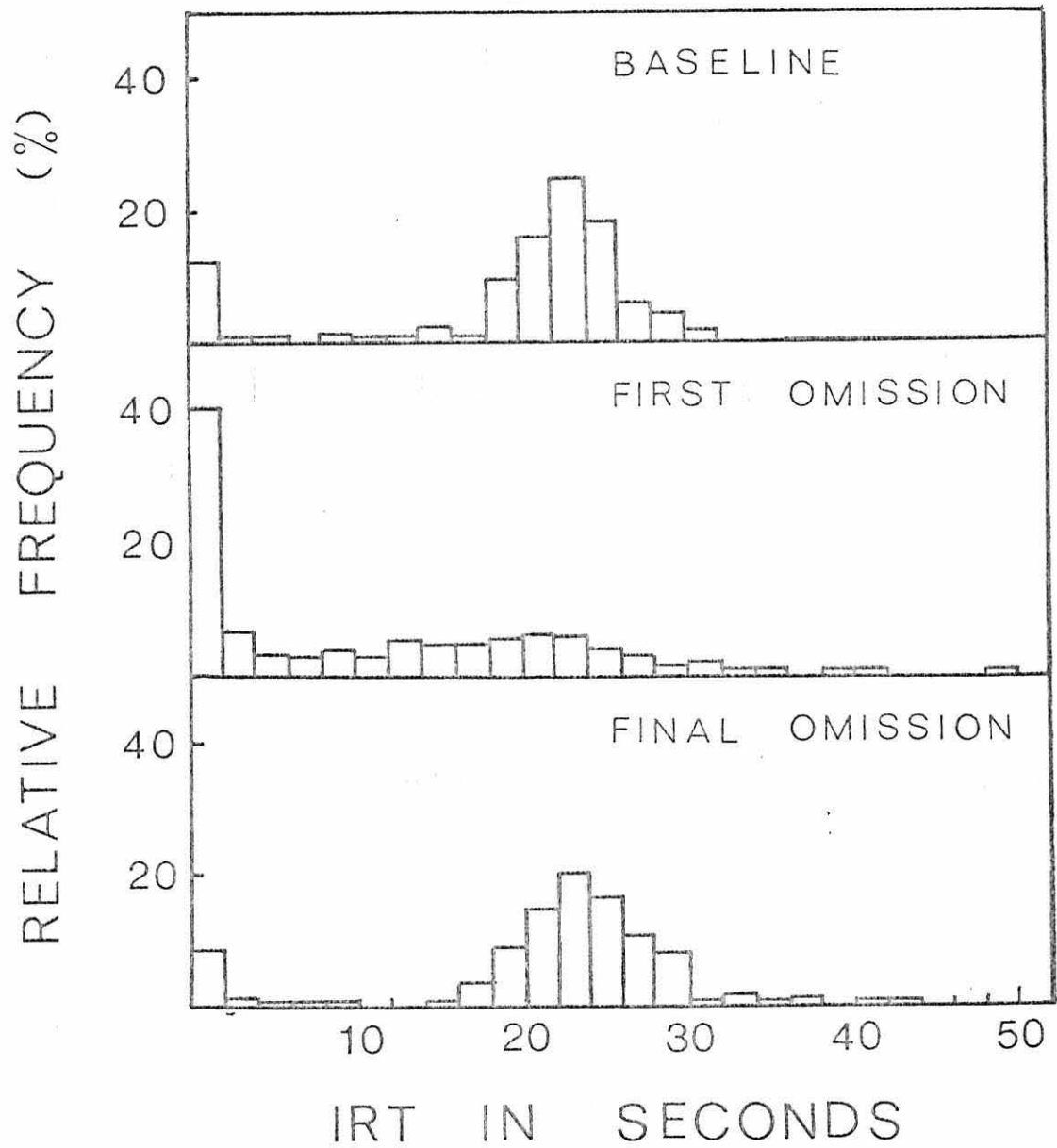final two sessions on the omission
condition (final omission).
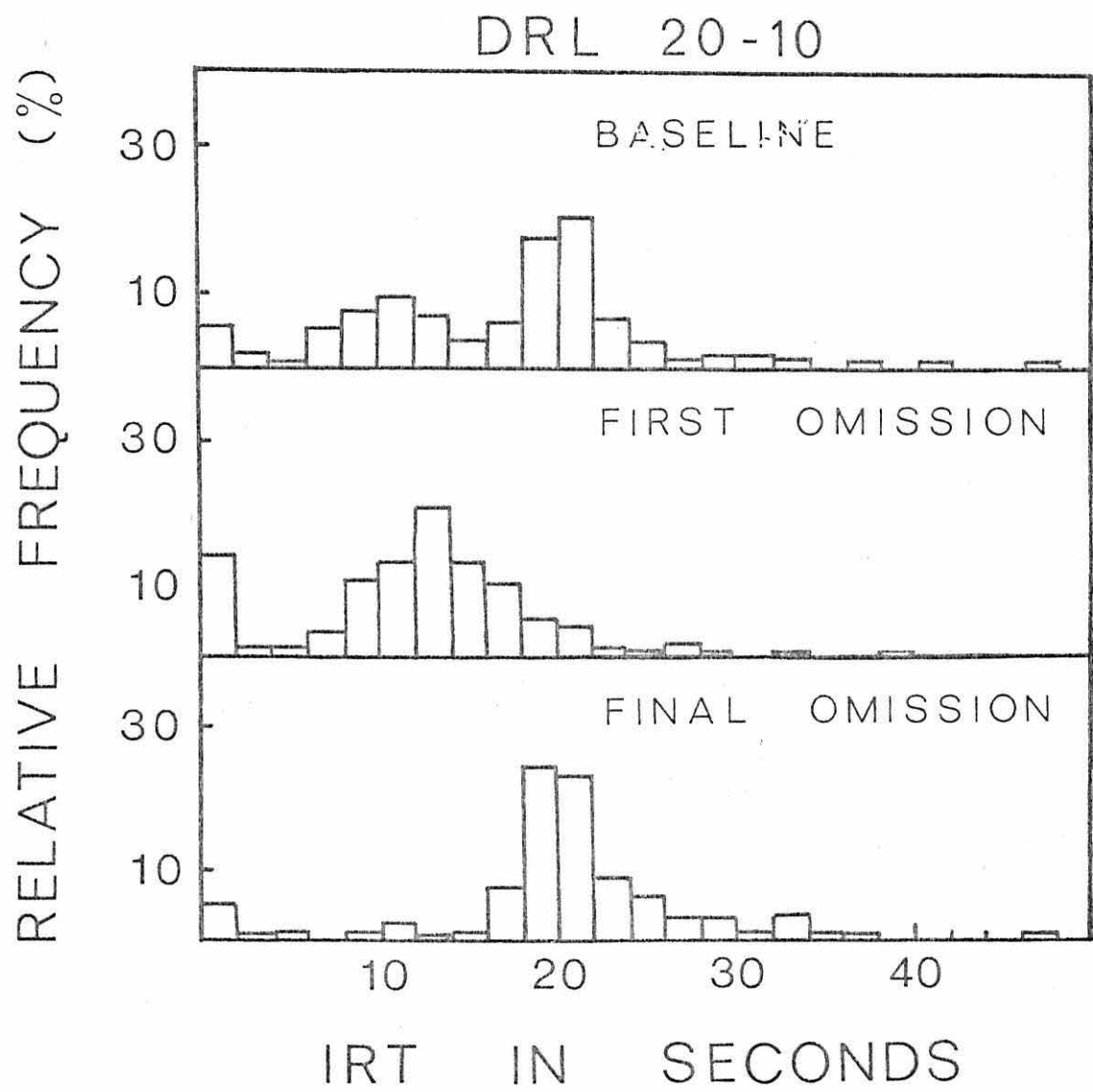
DRL 20-10

Figure 66. The overall relative frequency distributions of IRTs for Animal 140 from (i) the final two sessions on DRL 20-10 (baseline), (ii) the first session in which reinforcement was omitted from the t_2 component (first omission), (iii) the final two sessions on the omission condition (final omission).
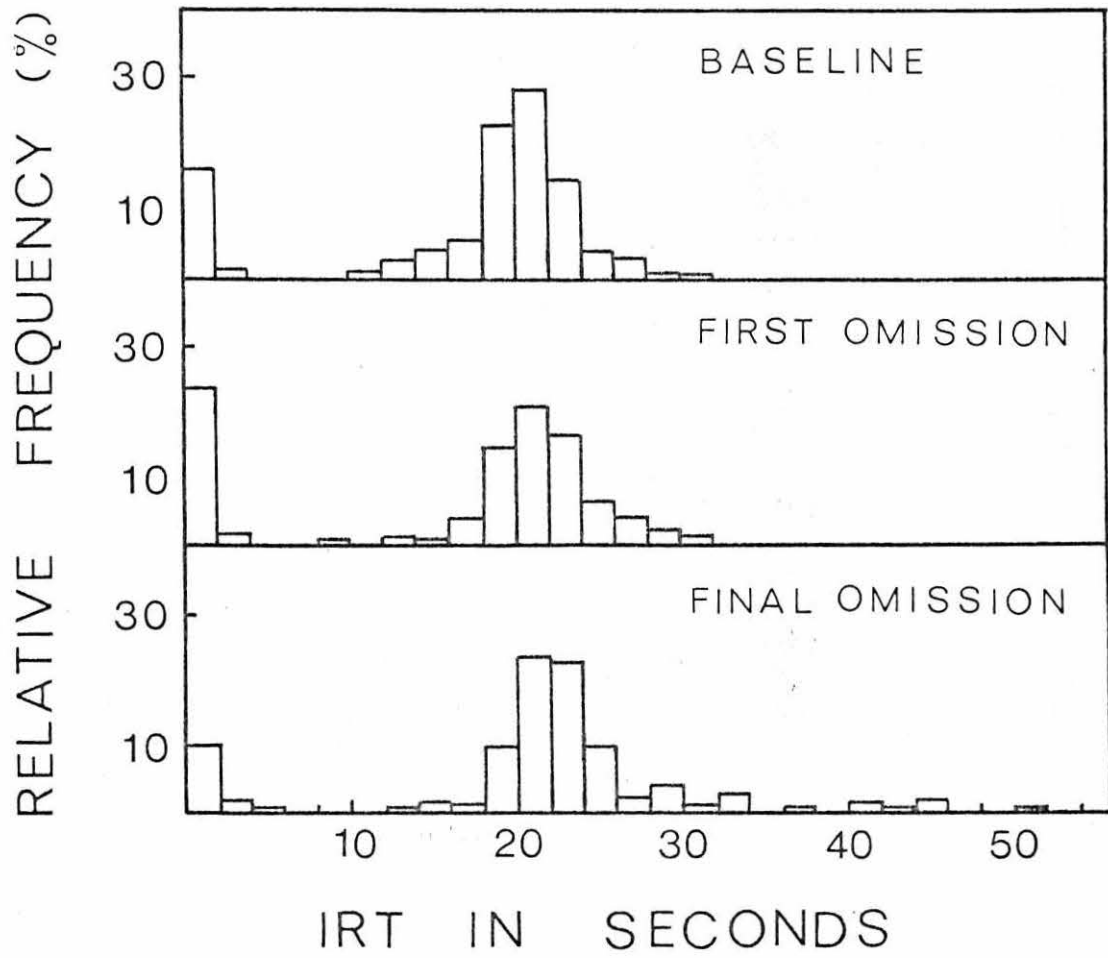
DRL 20-10
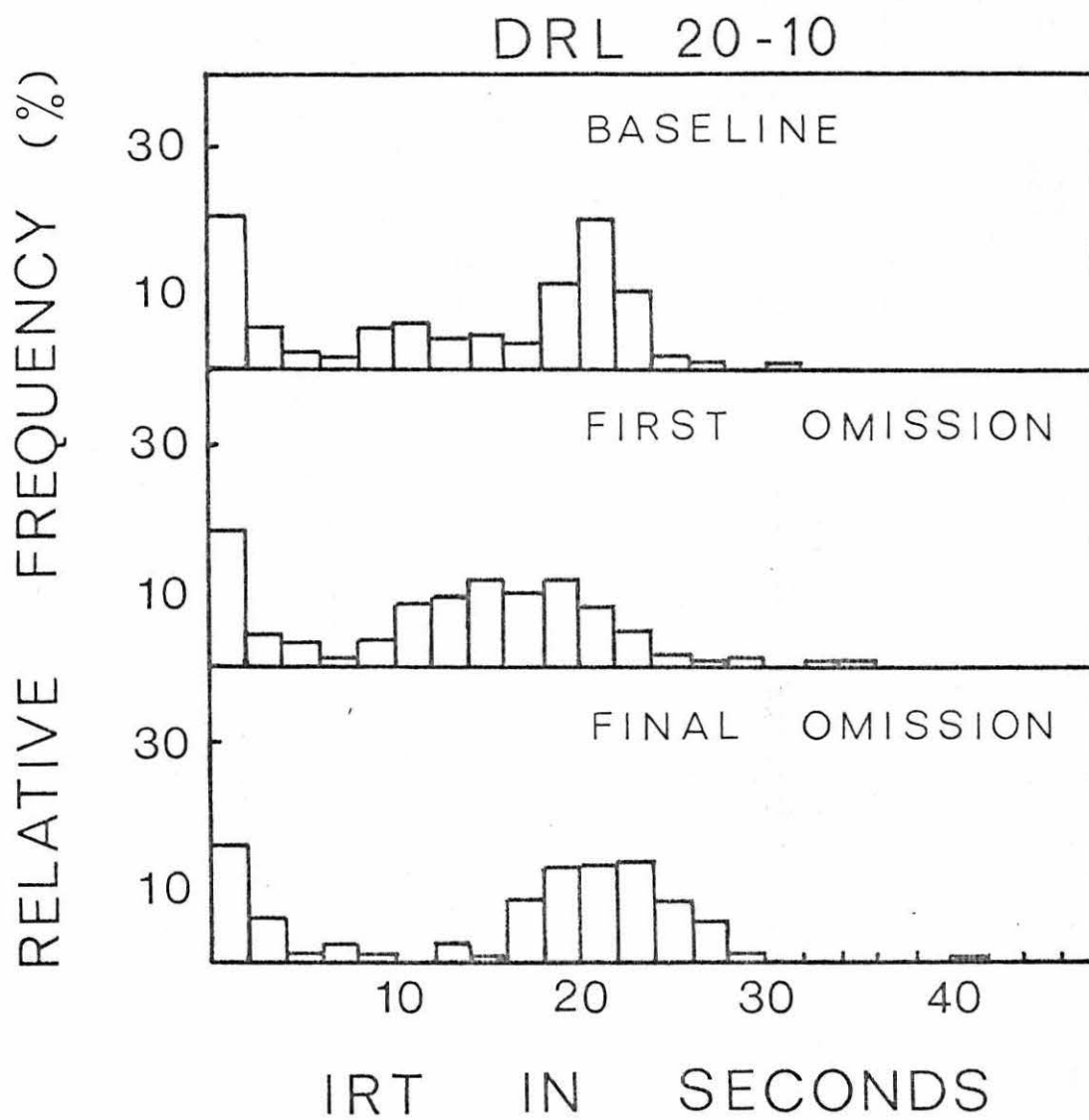
Figure 67. The overall relative
frequency distributions of IRTs for
Animal 109 from (i) the final two
sessions on DRL 20-20 (baseline),
(ii) the first session in which
reinforcement was omitted from the t_2
component (first omission), (iii) the
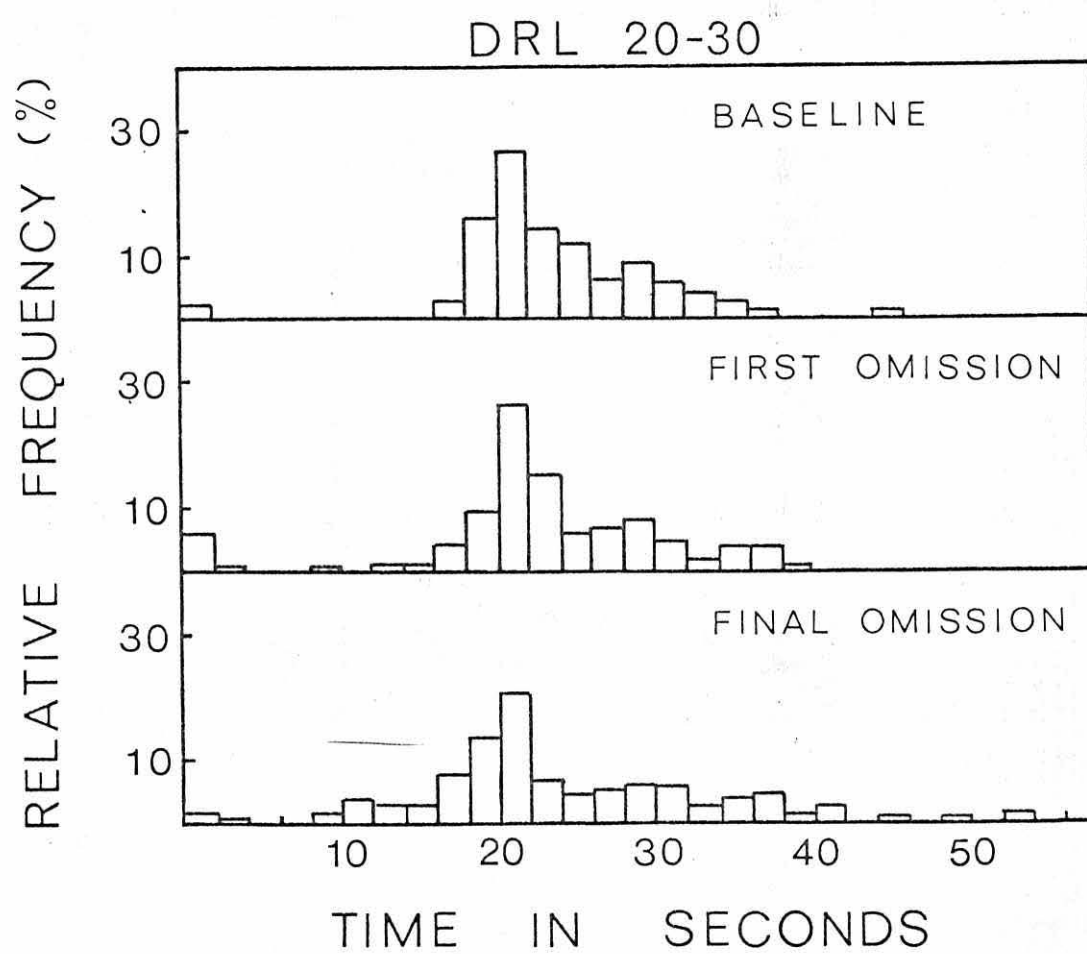final two sessions on the omission
condition (final omission).

DRL 20-20

Figure 68. The overall relative frequency distributions of IRTs for Animal 144 from (i) the final two sessions on DRL 20-20 (baseline), (ii) the first session in which reinforcement was omitted from the t_2 component (first omission), (iii) the final two sessions on the omission condition (final omission).

DRL 20-20

Figure 69. The overall relative
frequency distributions of IRTs for
Animal 102 from (i) the final two
sessions on DRL 20-30 (baseline),
(ii) the first session in which
reinforcement was omitted from the t_2
component (first omission), (iii) the
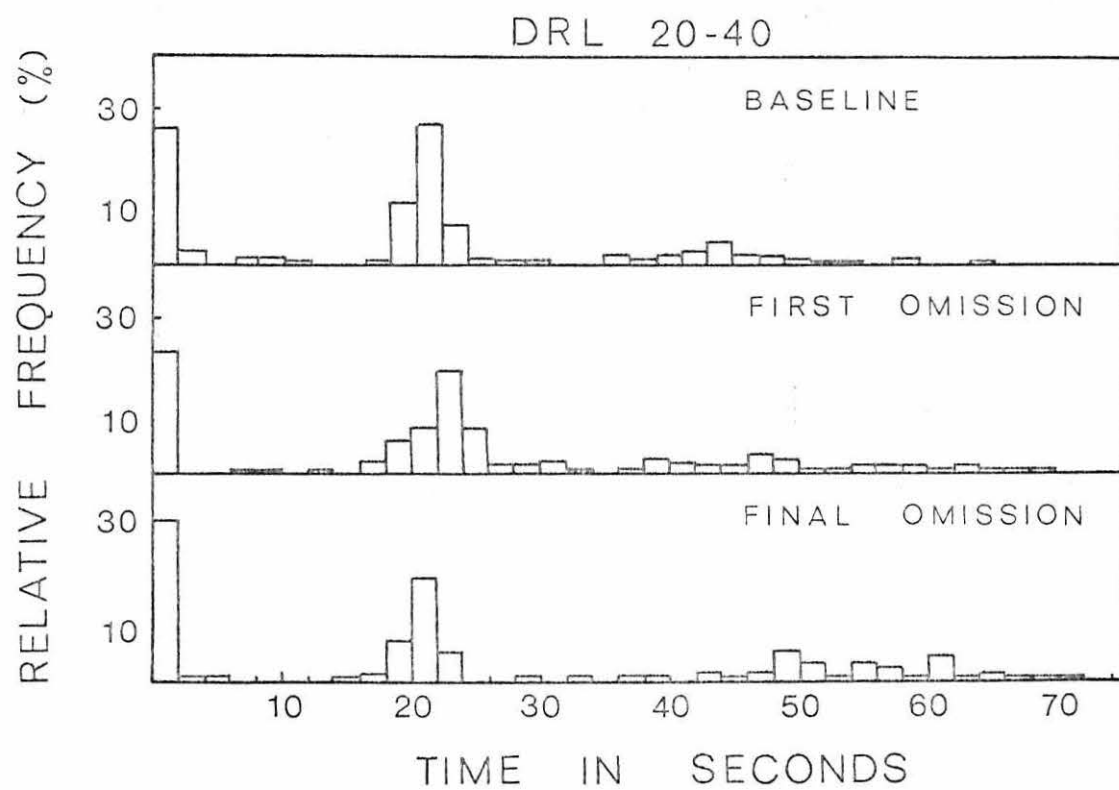final two sessions on the omission
condition (final omission).

DRL 20-30

Figure 70. The overall relative frequency distributions of IRTs for Animal 104 from (i) the final two sessions on DRL 20-40 (baseline), (ii) the first session in which reinforcement was omitted from the t_2 component (first omission), (iii) the final two sessions on the omission condition (final omission).

Figure 71. The overall relative
frequency distributions of IRTs
for Animal 106 from (i) the final
two sessions on DRL 20-60 (baseline),
(ii) the first session in which
reinforcement was omitted from the t_2
component (first omission), (iii) the
final two sessions on the omission
condition (final omission). IRTs longer
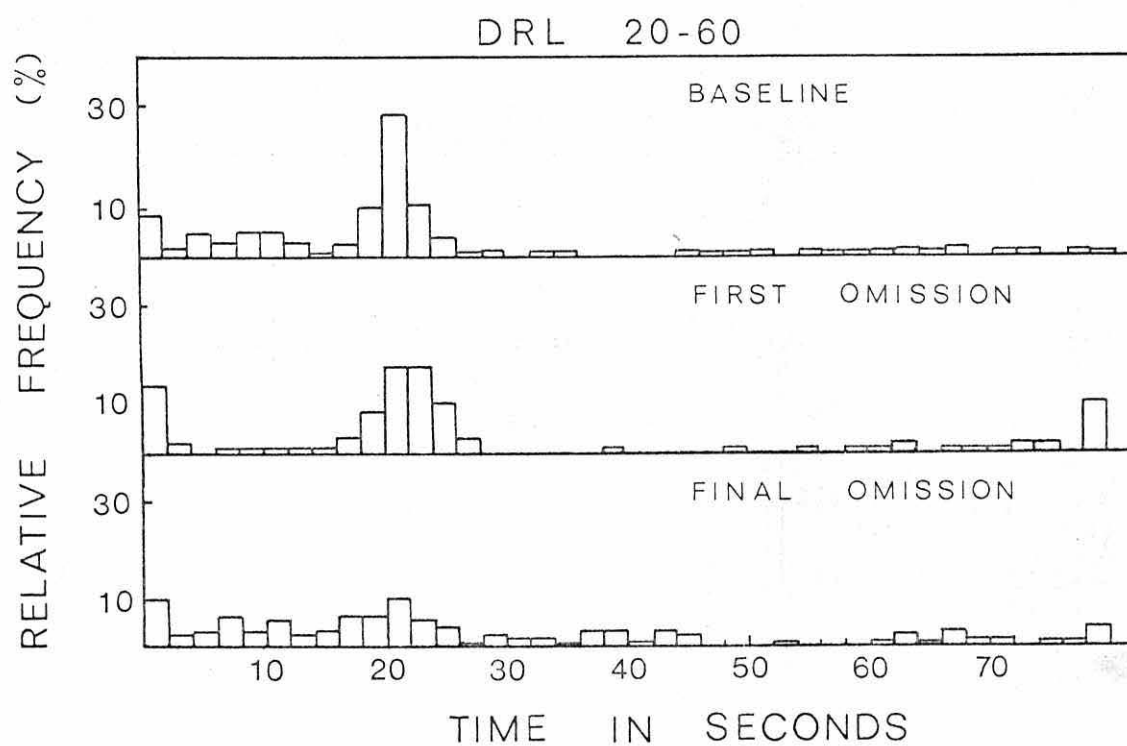than 78 sec are contained in the final
IRT category.

DRL 20-60

Figure 72. The overall relative
frequency distributions of IRTs for
Animal 112. The data are from the
final two sessions on each of the five
experimental conditions: (i) DRL 10-10,
(ii) response-initiated DRL 10 (FR 1 DRL 10),
(iii) response initiated DRL 10 with a
stimulus (light) added to IRTs which
followed reinforced responses (t+), (iv)
response-initiated DRL 10 with the stimulus
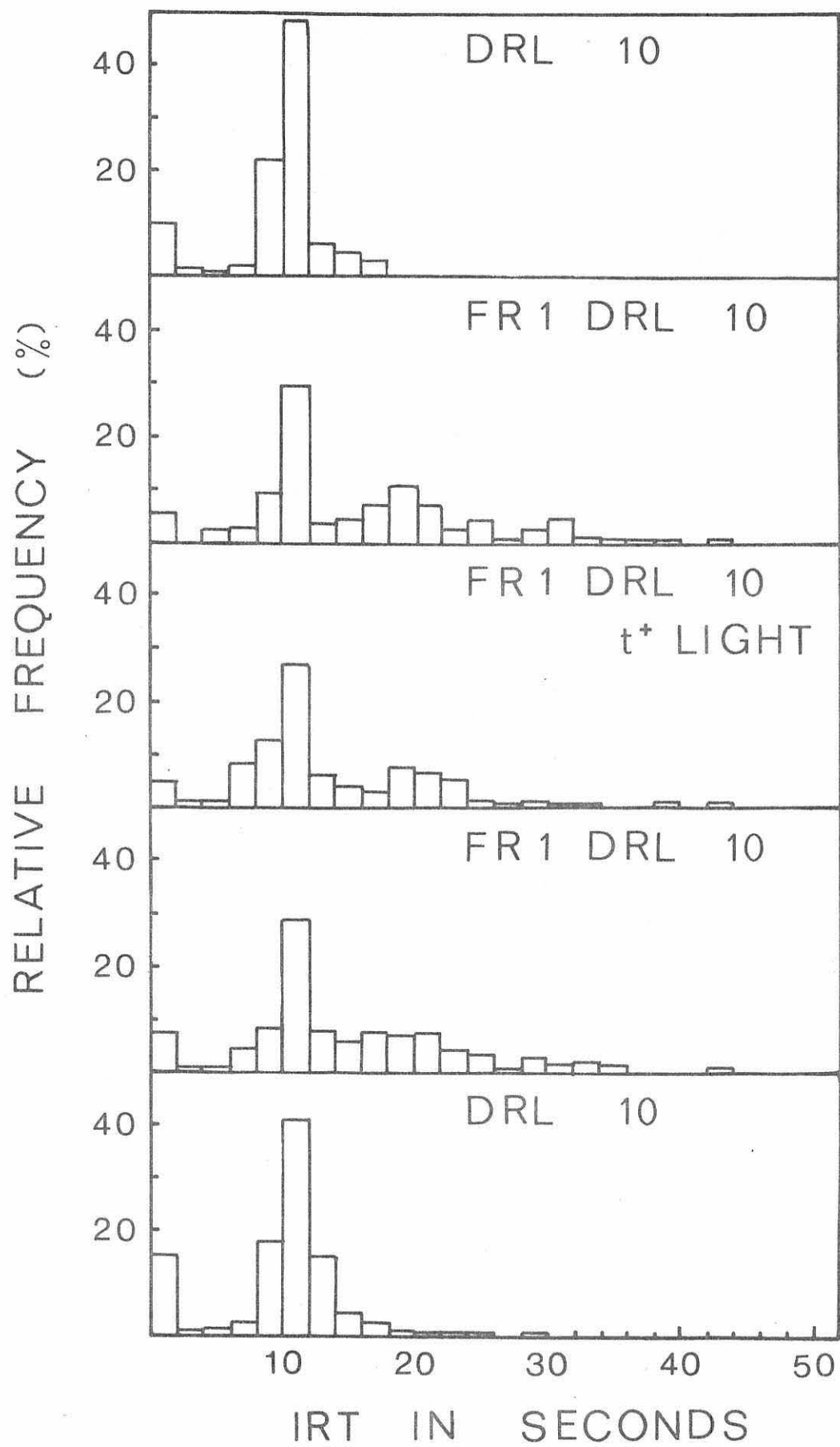removed, (v) DRL 10-10.

Figure 73. The overall relative
frequency distributions of IRTs for
Animal 114. The data are from the
final two sessions on each of the five
experimental conditions: (i) DRL 20-20,
(ii) response-initiated DRL 20 (FR 1 DRL 20),
(iii) response-initiated DRL 20 with a
stimulus (light) added to IRTs which
followed non-reinforced responses (t-),
(iv) response-initiated DRL 20
with the stimulus removed, (v) DRL 20-20.
IRTs longer than 78 sec are contained in the
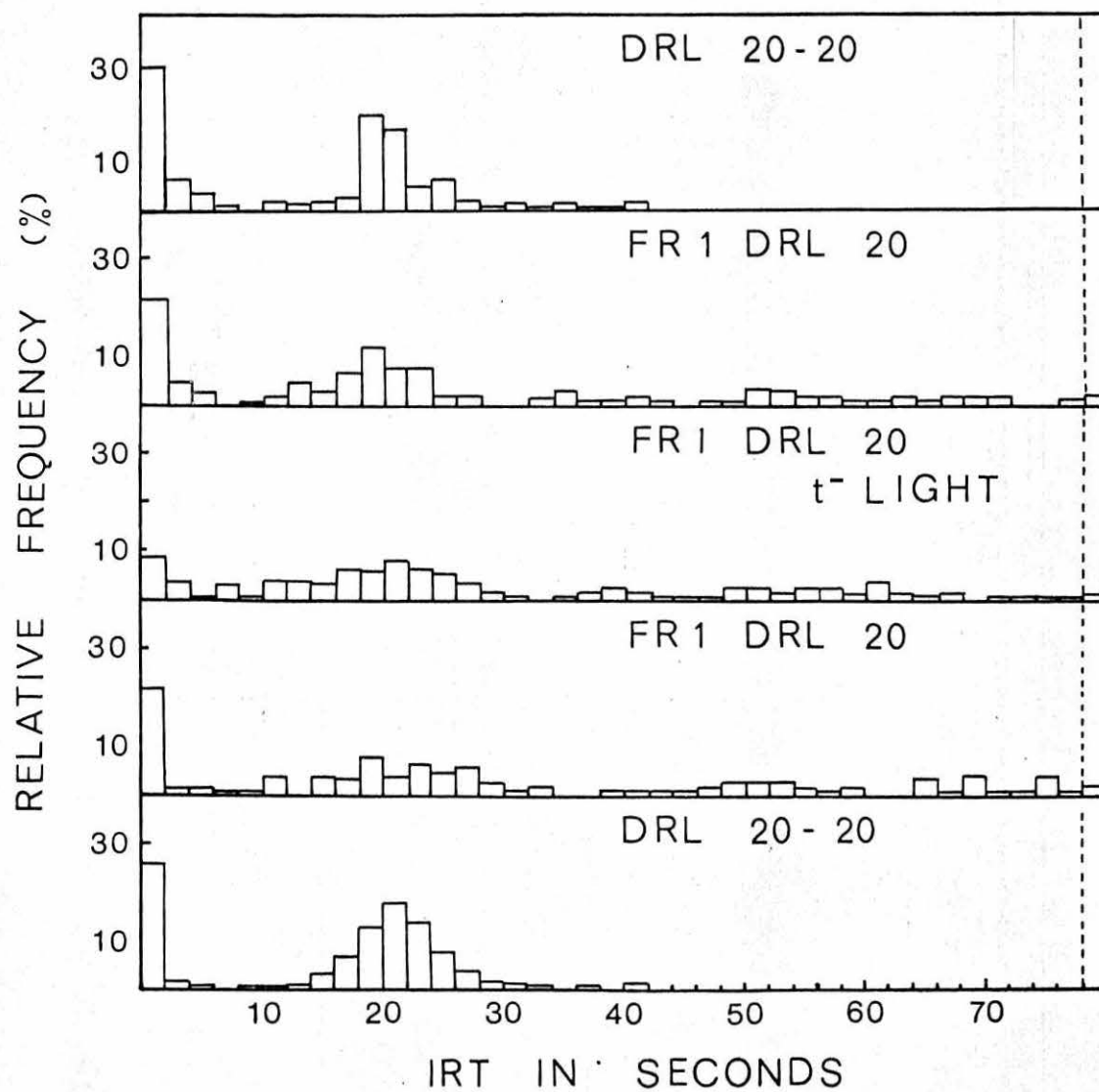final IRT category.

Figure 74. The overall relative frequency distributions, with different reinforcer concentrations. The data are from the test sessions on each schedule for each subject.