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### **Stimulus effects of reinforcement on variable-interval and variable-ratio schedules of reinforcement.**

Priddle-Higson, Peter John

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STIMULUS EFFECTS OF REINFORCEMENT ON  
VARIABLE-INTERVAL AND VARIABLE-RATIO  
SCHEDULES OF REINFORCEMENT

Peter John Priddle-Higson

Ph.D.

1976

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#### ABSTRACT

This study was mainly concerned with the effects of reinforcement upon the behaviour that immediately follows its occurrence. Rats' responding on a variable-ratio schedule and on three kinds of variable-interval schedule, namely, arithmetic variable-interval, constant probability variable-interval and arithmetic variable-interval with added short intervals, were investigated.

On the variable-interval schedules, the duration of the post-reinforcement pause was an increasing function of the magnitude of reinforcement. When some of the reinforcements were omitted, and a 'neutral' stimulus

presented in place of them, the pause following the stimulus was shorter than the post-reinforcement pauses. The local changes in the probability of reinforcement, with respect to the time-since-previous-reinforcement, on the schedules also affected the duration of the post-reinforcement pause. Changing the magnitude of the reinforcer or omitting the reinforcer did not systematically affect the rate and pattern of responding. The response rate was related, however, to the time that had elapsed since the preceding reinforcement. These relationships were also observed in the variable-ratio schedules. In the latter case the schedule parameter also affected the duration of the post-reinforcement pause. These results were discussed with reference to two hypotheses, viz. Amsel's frustration hypothesis and Staddon's discriminative control hypothesis.

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## CHAPTER 1

### INTRODUCTION

This thesis is concerned with an analysis of the stimulus properties of the reinforcer on schedules of reinforcement. In the experimental study of operant behaviour two classes of effective stimuli may be readily identified, reinforcing stimuli and discriminative stimuli. Historically the notion of a reinforcing stimulus is derived from Thorndike's (1911) original observations from experiments with hungry cats in puzzle boxes. Thorndike found that if the animal emitted some particular behaviour,

and this was followed by a 'satisfying' event, then the likelihood of that behaviour recurring was increased. Similarly, if the behaviour was followed by an event that caused discomfort to the animal, then the probability of that behaviour recurring was reduced. Thorndike formalised these observations into what he termed the Law of Effect which, simply, states that the behaviour emitted by an animal is controlled by the consequences the behaviour has for that animal. This statement of behavioural control provided the basis for Skinner's (1938; 1953; 1969) analysis of behaviour. However, instead of 'satisfiers' or 'rewards' and 'annoyers', Skinner adopted the term reinforcer, thus removing the hedonistic connotations attached to the above terms. A reinforcer is defined in terms of its relationship to some particular behaviour emitted by an organism, and may be defined as any stimulus, which when made contingent upon a specified response increases the future probability of that response. The symmetrical statement defines what has become termed punishment (Azrin and Holz, 1966). Skinner (1938) originally termed this negative reinforcement, however, this term is currently used to describe the increase in the probability of a response observed following the contingent removal of a stimulus.

In the study of the relationships between responses and reinforcers extensive use has been made by Skinner and his associates (Skinner, 1938; Ferster and Skinner, 1957) of schedules of reinforcement. These arrange for the

intermittent reinforcement of a response, and are defined in terms of the minimum requirements necessary for a response to be followed by reinforcement. Schedules of reinforcement are, usually, defined with regard to either the minimum times between successive opportunities for a response to produce reinforcement (interval schedules) or the number of responses the organism has to emit to produce reinforcement (ratio schedules). These schedules as well as various combinations of simple schedules are described in detail by Ferster and Skinner (1957).

Taking the other class of effective stimuli; a discriminative stimulus may be defined as a stimulus in the presence of which a response is reinforced (usually on the basis of some schedule of reinforcement) and in the absence of which the response goes unreinforced (Skinner, 1938). Consequently, a discriminative stimulus comes to exert control over the occurrence or non-occurrence of a response. This is what is generally implied by the term "stimulus control" (e.g. Terrace, 1966; Ferster and Perrot, 1968).

To some extent these two classes of stimuli, namely discriminative stimuli and reinforcing stimuli, have been treated as distinct and separate events. Discriminative stimuli have been regarded as exerting



antecedent control over subsequent responding and reinforcing stimuli as acting as consequent stimuli, 'strengthening' or increasing the future probability of a specified response. Some attempts, however, have been made to integrate these two classes of stimuli into a single category of environmental events which may have one or more effects upon behaviour (e.g. Schoenfeld and Cole, 1973). Similarly, several studies have suggested that a discriminative stimulus can, under certain conditions, acquire properties similar to those of the reinforcing stimulus, that is, it can function as a conditioned reinforcer (cf. Kelleher and Gollub, 1962). Also, it has been suggested that responses themselves may acquire a stimulus effect, as in explanations of schedule phenomena in terms of response chaining (cf. Kelleher, 1966 a). However, one possibility that has been neglected is that the reinforcing stimulus, as well as acting as a consequence to behaviour, may also come to exert stimulus control over responding subsequent to its occurrence. For example, Reid (1958) found that following training on a continuous reinforcement schedule (i.e., where every response is followed by reinforcement), the delivery of a non-contingent reinforcement sets the occasion for a response. The evidence relating to the stimulus control exerted by the reinforcing stimulus on schedules of reinforcement has been reviewed by Staddon (1972 a), Davey (1975) and Lowe (1974).

Before proceeding, a distinction will be made between the forms of stimulus control, situational control and temporal control (Staddon, 1972 a).

Situational control is equivalent to what was previously described as the control exerted by a discriminative stimulus. For example, an instance of situational control would be the control by two or more stimuli of different rates of responding on a multiple schedule of reinforcement (i.e., a procedure involving two or more simple reinforcement schedules alternating in some manner and each associated with a differential exteroceptive stimulus). In this case there may be no relationship between the time of occurrence of each response and the temporal properties of the appropriate discriminative stimulus. The stimulus is present while the behaviour occurs and the behaviour may not occur or be reduced if the stimulus is not present. Operationally, this implies that a controlling relationship may be demonstrated between a stimulus and the occurrence of behaviour but not the time of occurrence.

The second type of stimulus control is termed temporal control and is defined thus:

"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 this relationship - no matter what the events A and B, no matter how long or short the time separating them, and no matter what other contextual dependencies (Staddon, 1972 a, p.213)".

This thesis is concerned with the relationship between a reinforcing stimulus and the response which follows it in time.

It is well documented that if temporal constraints are placed upon the occurrence of successive reinforcements then the organism's behaviour adjusts to these temporal parameters (Ferster and Skinner, 1957; Harzem, 1969). Such temporal adjustment has been taken as an indication that the organism has formed a temporal discrimination (Catania, 1970; Harzem, 1969; Morse, 1966). An example of this is the behaviour produced by a fixed-interval (FI) schedule of reinforcement. On FI schedules the first response to occur after a minimum, constant, time has elapsed since the preceding reinforcement is followed by reinforcement. Typically, this schedule produces a characteristic pattern of responding with a pause following each reinforcement, the post-reinforcement pause, followed by a positively accelerated response rate which continues until the occurrence of the next reinforcement. The post-reinforcement pause on FI schedules has been shown to occupy a period of time which is roughly a constant proportion of the inter-reinforcement interval (Schneider, 1969; Sherman, 1958) that is, approximately one third. Staddon (1972 a) has argued that this relationship is an example of temporal control exerted by the reinforcer. On FI schedules as a consequence of the discriminative relationships that each

reinforcement bears to subsequent reinforcement, the occurrence of reinforcement predicts a period of non-reinforcement which is relative to the duration of the inter-reinforcement interval and reinforcement, therefore, comes to exert temporal inhibitory control over subsequent responding. A similar analysis may be applied to fixed-ratio (FR) schedule performance. On FR schedules, because the animal cannot respond faster than a certain maximum rate, there will always be a minimum inter-reinforcement interval and this variable can gain discriminative temporal control over the animal's tendency to respond and, for the same reasons as with FI schedules, the reinforcer can acquire temporal inhibitory after-effects.

According to this account the nature of the control acquired by the reinforcing stimulus would appear to be dependent upon the discriminative relationships between successive reinforcements. On FR and FI schedules, owing to the regular nature of the temporal separation between successive reinforcements, the occurrence of the reinforcer predicts a period of non-reinforcement and, consequently, acquires inhibitory stimulus control. That is, either a period of non-responding (the post-reinforcement pause) or a low rate of responding is observed after its occurrence. If stimulus control of this kind is dependent upon the regularity with which the reinforcer occurs in time, then if the temporal distribution of the reinforcements is

varied the control should become weaker. It might, therefore, be expected that on variable-interval (VI) schedules the duration of the post-reinforcement pause would not show any orderly relationships with either the preceding inter-reinforcement interval or to the mean inter-reinforcement interval. The post-reinforcement pause on variable ratio (VR) schedules should be also unaffected by the times between reinforcements. The present thesis investigated whether or not these predictions were the case.

The previous literature relating to these phenomena will be reviewed in Chapter 2. In that chapter the basic effects of the schedules of reinforcement to be used in this study are also described, with special reference to the differences that are usually observed between the effects of various VI and VR schedules.

A series of experiments will be described in Chapters 4, 5, 6 and 7. In all these experiments the magnitude of the reinforcer was manipulated and some of the reinforcements were omitted. These manipulations were carried out on the following schedules of reinforcement:

- (i) An arithmetic VI schedule
- (ii) A constant probability VI schedule
- (iii) An arithmetic VI schedule with extra short intervals
- (iv) A variable-ratio schedule

On the VR schedule the size of the ratio was also varied.

In every case the data were analysed so as to provide the following measures: (i) the post-reinforcement pause, i.e., the time from the occurrence of reinforcement to the occurrence of the next response; (ii) the running rate, i.e., the response rate calculated by excluding the post-reinforcement pauses; and for the VI schedules (iii) the local rate, i.e., the response rate in successive portions of the inter-reinforcement interval.

## CHAPTER 2

### THE STIMULUS EFFECTS OF THE REINFORCER ON SCHEDULES OF REINFORCEMENT: A SELECTIVE REVIEW

As Reid has pointed out:

"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 (1957 p.202)".

The present chapter examines the evidence for the stimulus control exerted by the reinforcer on some of the basic schedules of reinforcement, namely, continuous reinforcement

(CRF) fixed-interval (FI), fixed-ratio (FR), variable-interval (VI), and variable-ratio (VR) schedules.

#### CONTINUOUS REINFORCEMENT

On a continuous reinforcement (CRF) schedule every response is followed by reinforcement. In a series of experiments Reid (1957) has demonstrated that the reinforcing stimulus on CRF, not only reinforces behaviour, i.e., has consequent stimulus effects, but also gains a degree of stimulus control over the response that it reinforces, i.e., has antecedent stimulus effects. In one experiment six rats were exposed to two sessions during which each bar press response was followed by reinforcement (CRF), this occurred a total of 40 times over the two sessions. Following this were three extinction sessions each lasting 30-min during which a bar-press response was never followed by reinforcement. At the end of the last extinction period, when the frequency of responding was minimal, a number of stimuli were presented, such as tapping the box, flickering the lighting and sounding a buzzer. None of these stimuli had any detectable effect on the rats' responding. A few minutes later, a pellet of food was dropped into the food dish. All the rats ate immediately and five out of six pressed the bar at least once during an observation period of 1-min following eating; no bar-pressing having occurred



during the equivalent observation period before the delivery of food.

In a second experiment Reid (1957) investigated the effects of the same procedure using pigeons as subjects. When a maple pea - the reinforcer - was dropped into the food pan during extinction, all the birds ate immediately and five out of six pecked at the response key within 10-sec of eating. 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. Again, no responding had occurred for any of the birds during the equivalent 10-sec period before the delivery of a free reinforcement. Human subjects were found to behave in a similar way. Two types of behaviour were examined; (i) the operation of a slot machine (an operant); and (ii) the eye blink response (a respondent). In both cases the delivery of a free reinforcement during extinction produced a recovery in the specified response.

It would appear from the results of these experiments that on CRF schedules the reinforcing stimulus not only increased the probability of the specified response, but also came to exert some degree of control over the occurrence of responses.

## FIXED-INTERVAL

On a fixed-interval (FI) schedule the first response after a specified interval of time has elapsed is followed by reinforcement. Usually on FI schedules each interval is timed from the occurrence of the preceding reinforcement, thus, the schedule arranges for a minimum, constant, time interval between successive opportunities for reinforcement. In practice the programmed and the observed inter-reinforcement interval values do not, generally, differ to any marked extent. Typically, the performance generated by FI schedules consists of a pause following each reinforcement, followed by a gradually accelerating rate of responding which continues until the occurrence of the next reinforcement. This pattern of pause and responding is frequently termed the fixed-interval scallop. (e.g., Ferster and Skinner, 1957). After extended exposure to relatively short fixed-interval values, a break-and-run pattern of behaviour is often observed (e.g., Schneider, 1969), i.e., a pause after reinforcement followed by a rapid transition to a constant rate of responding during the running time (the time from the first response following reinforcement, which terminates the post-reinforcement pause, until the occurrence of the next reinforcement). Given this typical pattern of pausing and responding, several measures may be used to assess the effects on FI performance of various experimental procedures. These include (i) the overall response rate; (ii) the post-reinforcement pause; (iii) the running response rate;

(iv) the time from the occurrence of reinforcement to the fourth response; (v) quarter life, i.e., the time taken up for the first one-fourth of the total number of responses in each interval to be emitted (Gollub, 1964; Herrnstein and Morse, 1957); (vi) the average response distributions, i.e., the response rate in successive portions of the fixed-interval averaged, usually, over a session; and (vii) index of curvature, which is a measure of the direction and the extent of the deviation of the pattern of responding between successive reinforcements from a straight line function (Fry, Kelleher and Cook, 1960). Dukich and Lee (1973) examined the sensitivity of these different measures, excluding the index of curvature, to changes in response patterning engendered by manipulating the fixed-interval value. They exposed rats to a mixed schedule, (i.e., there were no differential stimuli associated with the different schedule components), consisting of two FI schedule components of unequal length (i.e., a mix-FIx FIy schedule), and systematically varied the duration of the shorter FI component. They concluded that:

"At least two measures seem to be needed to describe fully changes in the pattern of FI responding. The present results suggest that either post-reinforcement pause or time to the fourth response in conjunction with running rate can be used to describe many changes occurring in FI response pattern (p.289)".

A number of studies of the pattern of responding produced by FI schedules have suggested that the post-

reinforcement pause and the running rate are separately determined. According to Schneider (1969) and Shull (1970a), 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 schedules has frequently been accounted for in terms of the antecedent effects of the reinforcer (Dews, 1970; Ferster and Skinner, 1957; Kling and Schrier, 1971; Nevin, 1973; Staddon, 1972a). According to Ferster and Skinner (1957) the reinforcing stimulus also serves as a discriminative stimulus on the FI schedule setting the occasion for non-reinforcement. They state:

"The stimuli 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 nonreinforcement. Very roughly speaking, the effect of reinforcement as a stimulus of this sort appears to last about 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)".

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 is applicable only to situations in which the stimulus has a positive discriminative function ( $S^D$  or  $S^+$ ), negative discriminative control also occurs when, in the presence of a stimulus ( $S^\Delta$  or  $S^-$ ), responses are not reinforced (Ferster and Skinner, 1957). On this basis the reinforcer on FI schedules function as a negative discriminative stimulus "setting the occasion for the non-reinforcement of responding".

It is possible that Ferster and Skinner's (1957) stipulations that a discriminative stimulus is a stimulus "in the presence of which" responding is reinforced, may have led them to hypothesise the presence of residual stimuli for approximately 30-sec after the occurrence of reinforcement and thus controlling a low rate of responding. However, pauses of a longer duration than 30-sec have been recorded. For example, Dews (1965) reported post-reinforcement pauses of more than 1 hour on long FI's of up to 24 hours. In addition there is evidence suggesting that the duration of the post-reinforcement pause is relative to the value of the FI schedule. For example, Schneider (1969) found that the duration of the post-reinforcement pause was a positive linear function of the fixed-interval duration, and also that the pause was an approximately constant fraction

of the time between reinforcements (i.e., one-third), at the different FI values. Similar effects have been reported by Harzem (1968), and Sherman (1959). In view of this evidence it is difficult to see how the ongoing effects of residual stimuli associated with the reinforcer can wholly account for the post-reinforcement pause on the FI schedule.

An alternative account of the discriminative properties of the reinforcer on fixed-interval schedules has been proposed by Staddon (1969; 1972a). On an fixed-interval schedule the occurrence of reinforcement is followed by a period of non-reinforcement which lasts as long as the interval specified by the schedule. Thus, on FI schedules the reinforcer is, usually, the best predictor of non-reinforcement, and is the stimulus with the lowest relative proximity to the next reinforcement. As a consequence the reinforcer acquires conditioned inhibitory\* after-effects, exerting temporal control over the duration of the pause following reinforcement. In other words, the reinforcer on FI schedules is a temporal inhibitory stimulus. According to Staddon (1972a):

"One desirable consequence of this analysis is that it does not require the postulation of special 'consummatory' inhibition, demotivation, satiation, or even 'salience' effects to account for the inhibitory after-effects of reinforcement. These effects are

\* An inhibitory stimulus in this context is defined simply as a stimulus that suppresses responding.

a consequence solely of the discriminative relationship ... that reinforcement bears to subsequent reinforcement (Pp.233-234)".

While the evidence considered above suggests that the duration of the post-reinforcement pause is a function of the time between reinforcements. It is possible, however, that changing the fixed-interval value produces changes in the duration of the post-reinforcement pause owing to the effect the interval duration has on the response rate. Several studies have attempted to separate the inter-reinforcement interval and the number of responses emitted in the inter-reinforcement interval in an attempt to identify the determinants of the post-reinforcement pause on FI schedules. Neuringer and Schneider (1968) exposed pigeons to FR and FI schedules; each response was followed by a blackout - all the lights in the experimental chamber were extinguished, this is termed Time Out (TO). On the FR schedule, manipulating the duration of the blackout caused the inter-reinforcement interval to change without effecting the number of inter-reinforcement responses. On the FI schedule the same procedure resulted in variations in the inter-reinforcement response but not in the inter-reinforcement interval. On the FR schedule the post-reinforcement pause duration increased linearly with increasing inter-reinforcement interval, whereas on the FI schedule it remained constant.

Farmer and Schoenfeld (1964) investigated the effects of changing the pattern of terminal responding on an FI



schedule. They added a differential reinforcement of low rate (DRL) contingency to an FI schedule in which a response was reinforced if (i) a given fixed-interval had elapsed since the preceding reinforcement, and (ii) the interval separating that response from the preceding response exceeded a specified time. This produced a reduction in the rate of responding during the running time but did not effect the duration of the post-reinforcement pause. Other procedures which have been employed are; 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, i.e., a conjunctive FR1 FI schedule (Shull, 1970b); changing the response unit from a single response to a fixed number of responses (Shull, Guilkey and Witty, 1972). In all these studies the duration of the post-reinforcement pause was found to be related to the time between successive reinforcements, regardless of any additional response/reinforcement contingencies.

Strong evidence for the inhibitory after-effects of the reinforcer on FI schedules comes from a study by Wilkie (1974), taken from a suggestion by Staddon (1969). In this study pigeons responded on an FI schedule in the presence of a stimulus, which consisted of a line projected onto the response key. Training sessions were followed by dimensional stimulus



control test sessions during which the orientation of the line presented throughout the fixed-interval was varied. U-shaped (inhibitory) gradients of responding, with minimum response 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 maximum 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 omitted at the end of an interval and replaced by a brief blackout stimulus. It was found that when the preceeding interval had ended in blackout, inhibitory gradients did not occur in the following interval. Wilkie's results suggest that inhibitory effects are present early in an interval on FI and that these are dependent upon the occurrence of the preceding reinforcement.

Similarly, several studies have shown 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 responding at that point in the interval (Flanagan and Webb, 1964; Heinrichs, 1968; Malone, 1971; Singh and Wickens, 1968). This suggests that the novel stimulus has a 'disinhibitory' effect early in the FI, disrupting the inhibitory after-effects of reinforcement (cf. Pavlovian 'disinhibition'). It is also

interesting to note that when a novel stimulus is presented later in the FI, the effect is to decrease the response rate (Heinrichs, 1968).

Another method that has been used to investigate the inhibitory after-effects of reinforcement is the presentation of a non-contingent reinforcer during the course of a fixed interval. An experiment by Logan and Ferraro (1970) adopted such a procedure. On a small number of probe-intervals they presented a 'free' reinforcer midway through the course of the 30-sec FI schedule. The effect of this reinforcer was to produce a pause and a subsequent pattern of responding similar to that which normally occurred when the animal was reinforced at the end of an interval. They concluded:

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

Further evidence that the reinforcing stimulus has inhibitory after-effects on FI schedules comes from studies where some of the scheduled reinforcements have been omitted, and a 'neutral' stimuli presented in lieu of reinforcement (e.g., Kello, 1972; Staddon and Innis, 1966; 1969). Generally, these studies have found that response rate is higher in the intervals following the 'neutral' stimulus than in those following reinforcement; the effect being due,

principally, to a reduction in the pause following the stimulus, relative to the duration of the post-reinforcement pause. These and other such studies will be considered in further detail later.

Several studies have investigated the effects of manipulating the magnitude of the preceeding reinforcer on the subsequent responding on FI schedules. There are a number of reviews which have dealt with this area of research (e.g., Bolles and Moot, 1972; Kling and Schrier, 1971; Lowe, 1974), therefore, in the present instance only those studies which have analysed the effects of different reinforcement magnitudes on the response patterning produced by FI schedules will be considered.

Staddon (1970a) analysed the effects of the preceeding reinforcement magnitude on the post-reinforcement pause and running rate produced by the FI schedule. He manipulated the duration of reinforcement with pigeons on an FI 60-sec schedule. Five different durations of access to grain were presented randomly within test sessions; these durations ranged from 1.3 to 9.0-sec. The duration of the post-reinforcement pause was a positive function of the preceeding reinforcer duration. Running rate, on the other hand, was an inverse function of the preceeding reinforcer duration.

Staddon (1970a) concludes that these findings indicate that the reinforcer has temporal inhibitory after-effects on FI schedules and that 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 different reinforcement magnitudes on FI. Rats were exposed to a multiple FI FI schedule, each complete cycle being separated by a variable T0 period (mean = 60-sec). Reinforcement consisted of access to water, and its duration was kept constant at the end of the second component, but was systematically varied in the first component. Each component was accompanied by a different stimulus. Each rat was run until the behaviour was stable on each of the three reinforcement durations used. Jensen and Fallon's results may be summarised as follows: (i) response rate in the first component increased as a function of the reinforcement magnitude which occurred at the end of that component; (ii) there was no systematic change in response rate in the second component, as a function of reinforcement magnitude on the first; and (iii) there was no systematic change in the 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: (i) there was no systematic change in response rate or index of curvature on the first component as a function of reinforcement magnitude in that component - response rate was uniformly lower than in the baseline (100% reinforcement) condition; (ii) 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; (iii) index of curvature increased following reinforcement as magnitude of reinforcement increased; and (iv) response rate tended to be higher than in baseline conditions following the omission of reinforcement.

In summary, in this experiment, in the baseline conditions, the presentation of a greater reinforcement magnitude at the end of an FI component, had the effect of increasing the response rate which preceded the reinforcement. Reinforcement magnitude 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 (1970a) findings.

The results of Jensen and Fallon's study suggests that the suppressive effects of reinforcement are most pronounced in contrasted reinforcement conditions, as prevailed for example, during the omission phases.

This latter point was directly investigated in a recent study by Harzem, Lowe and Davey. (1975). Rats were exposed to an FI 60-sec schedule with a solution of milk used as the reinforcer. Each rat was run on each of three different reinforcer concentrations (20%, 40% and 60%). These concentrations being presented in consecutive sessions until a stability criterion was reached. The duration of the post-reinforcement was positively related to the magnitude of the preceeding reinforcement at the transition sessions between the different reinforcer concentrations. However, once the response rates were stable on the different reinforcer concentrations these differences in the pause durations had largely disappeared (see also Jensen and Fallon, 1973). It would appear, therefore, that the effects of manipulating the magnitude of reinforcement are enhanced when the different magnitudes are presented, to individual subjects, in close temporal proximity to one another.

The findings of these studies (Harzem et al., 1975; Jensen and Fallon, 1973; Staddon, 1970a) are consistent since, in every case, following a greater magnitude of reinforcement the effect may be considered to be inhibitory, resulting in the

lower response rate in Jensen and Fallon's study and the longer post-reinforcement pause in the studies of Staddon (1970a) and Harzem et al., (1975). 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 propounded by Stebbins, Mead and Martin (1959) and Walker (1969) that the lower response rates following larger reinforcement magnitudes are a reflection of a better or improved temporal discrimination. These results are also in accord with the suggestion that increasing the magnitude of the reinforcer enhances its discriminative effect, producing a consequent improvement in the general precision of performance (Di Lollo, Ensminger and Notterman, 1965; Notterman and Mintz, 1965).

A study by Lowe, Davey and Harzem (1974) compared the effects of manipulating the concentration of a milk reinforcer on the performance produced by (i) a conventional FI schedule, and (ii) a response initiated FI schedule (cf. Shull, 1970b). In the latter schedule, the first response after a reinforcement initiated the fixed-interval. Consequently, the length of the inter-reinforcement interval was dependent upon the duration of the post-reinforcement pause. If the effect of a greater magnitude of reinforcement is to improve the precision of performance or to produce a more precise temporal pattern of responding, then on a response-initiated FI



schedule the duration of the pause should decrease when the reinforcer magnitude is increased. However, the reverse of this is the case. Lowe et al., (1974) found that on both the FI and response-initiated FI schedules the duration of the post-reinforcement pause increased as a function of the preceding reinforcer concentration, despite the fact that on the response-initiated FI schedule such increases resulted in the delay of the next reinforcement as well as an overall reduction in the frequency of reinforcement. On the FI schedule, the running rate was a positive function of reinforcer magnitude, whereas, on the response-initiated FI schedule no systematic relationship of this kind was observed.

In summary, the results of studies which have analysed the effects of manipulating the magnitude of reinforcement on the after-effects of the reinforcer on FI schedules are consistent with the notion that the reinforcer has inhibitory after-effects on FI schedules, and that increasing the magnitude of the reinforcer increases, or enhances, these after-effects.

Additional, though indirect, evidence that the reinforcer has inhibitory after-effects on FI schedules comes from studies which indicate 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, also, 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 (Azrin and Holz, 1966; Ulrich and Azrin, 1962; Ulrich, Daloney, Kucera and Colasaco, 1972). Richards and Rilling (1972) report that when pigeons were given the opportunity to attack a restrained target, their attack rates were higher when an FI schedule was in operation than during operant level sessions. The pigeons emitted more attack responses during the post-reinforcement pause than during the latter part of the interval. As inhibitory control has been frequently thought to be aversive (Hearst, 1972; Richelle, 1972; Terrace, 1966; 1972) it might be expected that on an FI schedule this behaviour should occur mostly in the supposed inhibitory period, i.e., the post-reinforcement pause. This was found to be the case.

Several kinds of behaviour have been shown to occur in the post-reinforcement pause on FI schedules, for example, if rats are given the opportunity to engage in drinking, they will drink large quantities of water, far in excess of their normal daily requirement (e.g., Falk, 1972; Hawkins, Schrot, Gittens and Everett, 1972). Similar effects ha

been reported when the fluid available to the animal is a solution of ethanol in water (e.g., Freed, 1971; Freed Carpenter and Hymowitz, 1970; Freed and Lester, 1970; Woods and Winger, 1971). This phenomenon of excessive drinking has been termed schedule-induced polydipsia and, unless restrictions are placed upon the opportunities for the animal to engage in drinking, it tends to occur during the early period following reinforcement (Gilbert, 1974; Flory and O'Boyle, 1972). Staddon (1975) states that:

"On fixed and variable-interval schedules, drinking typically occurs just after food delivery, and it can easily be shown that once behaviour has stabilised drinking is directly under the control of each eating bout; each bout of eating produces a bout of drinking".

There is evidence to suggest that the frequency and rate of drinking are related to the parameters of the FI schedule. For example, Falk (1966) found that the amount of water drunk by rats on FI schedules was an increasing function of the FI schedule value, reaching a maximum at approximately FI 180-sec and then decreasing.

The occurrence of polydipsic drinking on FI schedules is not necessarily dependent upon the occurrence of food reinforcement. Rosenblith (1970) ran rats on a second-order\*

\* On a second-order schedule the performance generated by one schedule, the component schedule, is treated as a unitary response and is reinforced according to a second schedule of reinforcement, the overall schedule, cf. Kelleher, 1966a.

FI schedule in which every completion of an FI 1-min schedule was followed by a brief stimulus; every third interval ended in the brief stimulus accompanied by food, i.e., an FR3(FI 1-min: S<sup>P</sup>) second order schedule. Rosenblith (1970) reported the occurrence of polydipsic drinking following food reinforcement and also during the intervals following the brief stimulus alone. Similar findings have also been reported by Wuttke and Innis (1972) and Sumner (1975), in the latter study polydipsic drinking was reported following a brief stimulus not paired with food, presented on a VR2(FI 1-min S<sup>n</sup>) second-order schedule.

Further support for the proposition that the reinforcer has discriminative and inhibitory properties on FI schedules comes from studies which have analysed the effects of omitting some of the scheduled reinforcements on FI; with the non-reinforced intervals ending in either no stimulus change or a brief 'neutral' stimulus. The study of the omission of reinforcement on FI schedules has stemmed from a variety of divergent interests and this diversity has led to a number of experimental procedures and methods of analysis. One of the earliest uses for which the reinforcement omission procedure was employed was in the study of conditioned reinforcement, Ferster and Skinner (1957) describe the way in which intermittency can be introduced into schedule of reinforcement by substituting some other event

for a percentage of the reinforcements. They suggested that this type of 'percentage reinforcement' schedule is of interest in the study of chaining and consequently conditioned reinforcement. Later workers have adopted this procedure to study the response maintaining properties of brief stimuli - stimuli either paired or not paired with reinforcement (e.g., Byrd and Marr, 1969; De Lorge, 1967; Kelleher, 1966; Marr, 1969; Neuringer and Chung, 1967; Stubbs, 1969; 1971; Thomas and Blackman, 1974). However, apart from its origin's in the percentage reinforcement procedure and conditioned reinforcement studies, the reinforcement omission paradigm has recently been utilised in a different capacity - to study what has come to be known as the reinforcement omission effect. The omission effect is the name applied to the well documented finding that the occasional omission of a previously scheduled reinforcer elevates the rate of subsequent responding.

Nonetheless, despite these divergent interests, one consistent feature of these studies is that, if a brief 'neutral' stimulus is presented at the completion of the non-reinforced intervals, as opposed to no stimulus change, then the subsequent pattern of responding bears a greater similarity to that following reinforcement than if the completion of the non-reinforced intervals was not accompanied by a stimulus change. This has been reported in reinforcement

omission studies (Kello, 1972; Staddon and Innis, 1966; 1969), for example, Kello (1972) exposed pigeons to an FI 2-min schedule with the reinforcement cycle consisting of extinction of the houselights and the key-light (blackout) together with the illumination of the food magazine and access to grain for a specified period. Once the pigeons' responding had stabilised, 50% of the scheduled reinforcements were omitted and the non-reinforced intervals ended in either (i) blackout + magazine light, (ii) blackout alone, or (iii) no stimulus change; each omission stimulus occurring with an equal probability. The response rate was consistently lower following reinforcement, somewhat higher following blackout + magazine light, higher still following blackout alone and highest following the unsignalled omission. These differences in response rate were almost totally accounted for by differences in the pauses following the different omission stimuli, i.e., the more similar the omission stimulus was to the reinforcement cycle the longer the pause following that stimulus. Similar effects have been reported by Staddon and Innis (1966; 1969). Staddon (1970b) in summarizing these latter experiments states that:

"If a brief stimulus blackout is presented in lieu of reinforcement, response rate over the following interval, though elevated with respect to rate following reinforcement, is depressed by comparison with rate following complete reinforcement omission. Thus blackout must be considered to have inhibitory after-effects under these conditions, although it is evidently not as inhibitory as reinforcement (p.229)".

Several studies using second-order schedules have compared schedules involving a brief stimulus paired with food presented at the completion of non-reinforced intervals with tandem conditions, i.e., a similar schedule but with no stimulus change marking the completion of non-reinforced intervals. These studies have reported (a) a change in the rates of responding when tandem schedules are changed to brief stimulus schedules (Byrd and Marr, 1969; De Lorge, 1967; 1969; Kelleher, 1966b; Marr, 1969), and (b) the within-component (interval) pattern of responding under the brief stimulus procedures comes to resemble the pattern of responding observed when the component terminates with food (Byrd and Marr, 1969; Kelleher, 1966b). Also, this effect has been reported when a brief stimulus, not paired with food, is presented at the completion of the non-reinforced intervals (De Lorge, 1967; Kelleher, 1966; Stubbs, 1971).

Stubbs (1971) using a second-order schedule procedure reported effects similar to those of Kello (1972). He found that on a second-order FI 300 (FI40:S) schedule, presentations of the key-light and houselight at the completion of non-reinforced intervals maintained superior FI scalloping, measured in terms of the index of curvature, to key-light alone or houselight alone, with blackout (no stimulus) maintaining the least degree of FI patterning.

It would, appear, therefore, that a 'neutral' stimulus presented in lieu of reinforcement on FI schedules, may acquire similar after-effects and control to that exerted by the reinforcing stimulus. The following factors appear to determine the extent to which a brief stimulus acquires after-effects similar to those following reinforcement. (1) The similarity of the omission stimulus to the reinforcing stimulus; the studies of Kello (1972) and Stubbs (1971) suggest that the extent of the after-effects of the omission stimulus varies in relation to its similarity to reinforcement, i.e., similarity in terms of the number of stimulus elements the omission stimulus has in common with the reinforcing stimulus complex. However, studies by, for example, Kelleher (1966a) and Stubbs (1971) suggest that differences in the after-effects of the stimulus occur when its similarity to reinforcement is varied extra-dimensionally (cf., Kello, 1972) and not when it is varied intra-dimensionally, i.e., with a stimulus which is either paired or not paired with food. (2) The duration of the omission stimulus; Staddon and Innis (1969) reported that response rate on FI varied as an inverse function of the duration of the preceeding T0 for both rats and pigeons. This function was only obtained for rats during the first five sessions of omission testing, the effect of the omission stimulus duration dissipating with practice. However, at longer stimulus durations (16-32-sec) both rats and pigeons showed a slight increase in subsequent response rate. The



changes in response rate were found to result almost solely from changes in the post-stimulus pauses rather than from decreases or increases in running rate, which remained relatively stable. Cohen, Hughes and Stubbs (1973) using a VI 240 (FI 48:S) second-order schedule, found that FI patterning (as measured by the index of curvature) was a function of the duration of the preceeding brief stimulus. This increase in the index of curvature may have reflected a lengthening of the post-omission pause as the duration of the omission stimulus was increased, results which would be consistent with the findings of Staddon and Innis (1969).

(3) The parameter of the schedule; the magnitude of the omission effect on FI schedules has been shown to be a function of the value of the schedule. Starr and Staddon (1974) found that the difference between the pause following the omission stimulus and the post-reinforcement pause was substantial at FI 2-min, at FI 30-sec it was much smaller and at FI 15-sec almost negligible. (4) The magnitude of reinforcement; it has been demonstrated that the extent of the reinforcement omission effect depends upon the magnitude of reinforcement in effect (Jensen and Fallon, 1973; Harzem et al., 1975). In the latter study rats responding on an FI 60-sec schedule were run to stability on each of three different reinforcement magnitudes (20%, 40% and 60%). Following this 50% of the scheduled reinforcements were omitted and a stimulus presented in lieu of reinforcement. The duration of the post-reinforcement pause was found to be



an increasing function of the magnitude of reinforcement, whereas the duration of the post-omission pause was inversely related to the reinforcement magnitude. (5) The sequencing of reinforced and non-reinforced intervals; Thomas (1970) found that when reinforced and non-reinforced fixed-intervals were presented in strict alternation, the omission effect, measured in terms of both the post-event (reinforcement or stimulus) pause and running rates, was greater than when reinforced and non-reinforced intervals occurred in a random manner. The extent of the omission effect, therefore, would appear to be related to the probability of a non-reinforced interval being followed by reinforcement. Staddon (1972a, p.234) reports an experiment in which intervals ended in reinforcement or a stimulus with an equal probability, but with the conditional probability ( $p$ ) of an interval both beginning and ending with non-reinforcement being  $p = 0.9$  under one condition, and  $p = 0.1$  under another. The pause following the omission stimulus was longer under the  $p = 0.9$  condition than under the  $p = 0.1$  condition, suggesting that the higher the probability that non-reinforcement is followed by reinforcement the greater the omission effect. But even so, the omission effect was always observed, the pause following reinforcement being always longer than the pause following non-reinforcement, even under the  $p = 0.9$  condition, where reinforcement almost invariably was followed by reinforcement and non-reinforcement by non-reinforcement.

In summary, although the extent of the after-effects of a stimulus presented in lieu of reinforcement depends upon the several factors, as described above, the stimulus does not appear, except possibly under special circumstances, to acquire inhibitory after-effects to the same extent as the reinforcer. According to Staddon (1972a) the longer pausing which occurs following reinforcement than that following the stimulus is due to memory; the animals remember the reinforcing stimulus better than another stimulus and the former, therefore, inhibits responding for a longer period of time (Staddon 1972a, has attributed this difference to the greater biological importance of the reinforcer). 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. A study by Davey, Harzem and Lowe (1975) has shown that changes in the magnitude of the reinforcer on an FI schedule are functionally similar to changes in the intensity of a 'neutral' stimulus. Rats responded on a second-order VR2(FI60:S<sup>n</sup>) schedule; under one test condition the intensity of the neutral stimulus was held constant and the magnitude of the reinforcement varied, and under the other test condition the magnitude of the reinforcer was held constant and the intensity of the stimulus varied. The duration of the post-reinforcement pause was positively related

to the magnitude of the reinforcer, and likewise the duration of the post-stimulus pause to the intensity of the stimulus. The authors' concluded:

"While it seems plausible to talk of the 'value' of various amounts of food, the concept is more difficult to relate to various intensities of tone. There are no independent grounds to suppose that in this experiment the tone at 90db was more valuable than at 80db, and so on (p.222)".

According to Staddon (1972a) if a 'neutral' stimulus were to be the best predictor of non-reinforcement such a stimulus would gain inhibitory temporal control over subsequent responding and this would be particularly strong evidence in support of the discriminative hypothesis. An experiment cited by Staddon (1972a) satisfies these requirements. Pigeons were exposed to a VI 1-min schedule into which an FI 2-min schedule was occasionally interpolated. This procedure was organised in terms of 4-min cycles; the first 2-min of each cycle was the VI 1-min baseline schedule; at the completion of 2-min the key-stimulus changed from white (W) to white with three vertical bars superimposed onto it (WV). This brief stimulus was presented independently of the pigeons behaviour, lasted for 5-sec and was followed by a return to the W key-light. The next reinforcement after each occurrence of WV was delivered on an FI 2-min schedule. This cycle was then repeated. Under these conditions, reinforcement predicted reinforcements on a VI 1-min basis, but WV predicted a 2-min period of non-reinforcement. Under this procedure Staddon reported good inhibitory

control by the WV stimulus, despite its similarity to the W baseline stimulus.

In conclusion, the evidence presented in this section is consistent with the premise that the reinforcing stimulus has inhibitory after-effects on FI schedules, and suggests that these after-effects are a consequence of the discriminative relationships that reinforcement bears to subsequent reinforcement on the FI schedule.

#### FIXED RATIO

In a fixed-ratio (FR) schedule the last of a specified number of responses is followed by reinforcement, the number of responses being constant from one reinforcement to the next. Typically the performance on FR schedules is characterised by a pause after reinforcement followed by a relatively high and constant rate of responding which continues until the occurrence of the next reinforcement (Catania, 1968; Nevin, 1973).

The reinforcement on FR schedules may act as a discriminative stimulus, as a response is never reinforced immediately after a reinforcement (Ferster and Skinner, 1957). Thus the operation of the food magazine and ingestion of the food are stimuli which set the occasion

for the absence of reinforcement and as such control a low rate of responding. Also Ferster and Skinner (1957) point out, as with any other stimulus the  $S^\Delta$  effect of the reinforcing stimulus on FR schedules may extend beyond its termination. In other words, the reinforcer on FR schedules is the best predictor of non-reinforcement and, as a consequence, may acquire discriminative control over subsequent responding.

The duration of the post-reinforcement pause on FR schedules is related to the ratio requirement of the schedule. Felton and Lyon (1966) exposed pigeons to various values of an FR schedule, ranging from FR 50 to FR 150. In all instances the duration of the post-reinforcement pause increased as a function of the ratio requirement specified by the schedule. A similar relationship between the duration of the post-reinforcement pause and the fixed ratio requirement has been reported by both Boren (1961) and Powell (1968). Both Felton and Lyon (1966) and Powell (1968) found that the running response rate tended to decrease with increasing ratio value, however, in both studies there was considerable inter-subject variability in this effect. Also, in Felton and Lyon's experiment, examination of the cumulative records they present suggests that the lower running rate observed on the higher fixed-ratio values may have been due to the incidence of relatively long pauses during the running time. On the basis

of their findings, Felton and Lyon (1965) concluded that the performance produced by the FR schedule would be better considered in terms of (1) the pause following reinforcement, and (2) responding during the running time; rather than in terms of the overall rate of responding.

The question of what variables control the duration of the post-reinforcement pause on FR schedules is not answered by the above studies. It is possible that either; (i) the number of responses in an FR schedule may, as well as the reinforcing stimulus act as a discriminative stimulus controlling the duration of the post-reinforcement pause (Ferster and Skinner, 1957); (ii) the time since reinforcement may be a controlling factor as, following reinforcement, a response cannot be reinforced in a period of time less than that required by the animal to emit the ratio requirement - this period of time has been shown to co-vary with the response requirement of the schedule (Ferster and Skinner, 1957; Nevin, 1973); or (iii) that both of these factors are involved in determining the post-reinforcement pause.

Even though an FR schedule does not directly specify a minimum interval between reinforcements it appears that the duration of the post-reinforcement pause may, nevertheless, be determined by the inter-reinforcement interval. For example, Berryman and Nevin (1962) trained

rats on an FR schedule, an FI schedule, and four interlocking\* schedules until stability was reached in the rates of responding. In all instances performance was characterised by a pause following reinforcement, which was a constant fraction of the time between reinforcements, regardless of whether reinforcements were programmed on a ratio schedule, an interval schedule, or on an intermediate interlocking schedule.

Neuringer and Schneider (1968) attempted to evaluate the relative importance of the inter-reinforcement time and the number of responses between reinforcements in determining the duration of the post-reinforcement pause. They varied both factors independently, scheduling brief T0's after each non-reinforced response. By manipulating the duration of these T0's they were able, on the FR schedule, to produce variations in the inter-reinforcement interval without changing the response requirement. On the FI schedule lengthening the T0's reduced the total number of responses in the interval but did not effect the duration of the inter-reinforcement interval. They found that on the FR schedule the duration of the post-reinforcement

\* 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 quickly reinforcement is 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 increasing inter-reinforcement interval, whereas the duration of the post-reinforcement remained constant on the FI schedule despite a reduction in the number of responses emitted by the subject during the interval. It seems that:

"...the time between reinforcements controls responding independently of the number of responses emitted during that time (Neuringer and Schneider, 1968, p.666)".

Similar effects were noted by Killeen (1969) using pigeons yoked together in pairs\*. The 'master' birds were placed on different values of an FR schedule, while the yoked 'slave' birds received reinforcements on an FI-like basis, although the intervals were not precisely constant. There was no difference between the post-reinforcement pause durations of the pigeons responding on the FR schedule and the yoked control birds on the FI schedule. Further, although indirect, evidence to suggest that the duration of the post-reinforcement pause on FR schedules is controlled by temporal factors comes from a study by Shull, Guilkey and Witty (1972) which investigated the effects of varying the response requirement on FI schedules. They exposed pigeons to an FI (FR:S) second-order schedule and examined the effects of varying both the FI overall schedule value and the FR component

\* In a yoked procedure two experimental chambers are connected so that the scheduling of reinforcements and/or stimuli for the subject in one chamber (the 'slave' subject) are controlled by the performance of the subject in the other chamber (the 'master' subject),



schedule. Generally, the duration of the post-reinforcement pause was a function of the time between reinforcements, i.e., the FI value, and was not related to the value of the FR component schedule.

In summary, the above studies suggest that on FR schedules, the duration of the pause after reinforcement is primarily determined by the duration of the inter-reinforcement interval and not by the ratio requirement. However, a recent study by Crossman, Heaps, Nunes and Alferink (1974) in which subjects were presented with different FR values in a multiple schedule, suggests that in some situations the ratio requirement may nevertheless affect the duration of the post-reinforcement pause. It is possible, however, that their findings were affected by the fact that a different stimulus accompanied each of the ratio schedules.

Support for the proposition that the reinforcer has inhibitory after-effects on FR schedules comes from studies where some of the scheduled reinforcements have been omitted (e.g. Henke, 1973; McMillan, 1971). McMillan (1971) investigated the effects on pigeons' responding on an FR schedule of randomly omitting various percentages of the scheduled reinforcements and presenting a neutral stimulus (a 4-sec T0) in lieu of reinforcement. In all instances

there was an increase in the overall response rate following the omission stimulus compared to the response rate following reinforcement. This increase in overall response rate was due, principally, to a reduction in the duration of the pause following the omission stimulus compared to the duration of the post-reinforcement pause, and not to changes in the running response rate once the subjects had commenced responding. Similar effects have been reported by Davidson (1969) using a slightly different procedure. Rats were exposed to a second-order FR6(FR6:S) schedule where, at the completion of each FR6 component, a brief food-paired stimulus (a T0) was presented; after the sixth FR6 component food was presented in addition to the brief stimulus.

Davidson's procedure differed from McMillan's on two main points. Firstly, reinforcement and non-reinforcement in Davidson's study were presented in a fixed sequence, whereas in McMillan's study the two events occurred randomly at the completion of each ratio requirement. Secondly, the data from Davidson's experiment were taken from the last few sessions after the subjects' behaviour had stabilised, whereas in McMillan's experiment the data were collected during the last few sessions with 100% reinforcement and the first few sessions of reinforcement omission, and likewise with the other percentages of

reinforcement omission studied. Nonetheless, Davidson also reported a shorter pause following the brief stimulus than following reinforcement, however, the duration of the post-stimulus pause tended to decrease over successive FR components. He also analysed the mean durations of successive IRTs in the first, third and sixth components of the FR6(FR:S) schedule. Mean IRT was constantly less in the third component than the first and similarly, less in the sixth component than the third, thus indicating that response rate tended to increase over successive FR6 components irrespective of differences in the pause duration. Although not in agreement with McMillan's findings, this effect was slight and may have been a consequence of the manner in which reinforced and non-reinforced ratios were alternated in strict sequence.

Several other studies have investigated the effects of omitting some of the scheduled reinforcements on FR schedules within the framework of second-order schedules. For example, Davidson (1969) and Shull et al., (1972) investigated an FI (FR:S) schedule; Neuringer and Chung (1967) used a VI (FR:S) schedule; and Blackman, Thomas and Bond (1970) and Stubbs (1971) an FR (FR:S) schedule. Generally, these studies have been concerned with the ability of a brief stimulus, either paired or not paired with reinforcement, to maintain a similar pattern of responding as does reinforcement, i.e., the conditioned reinforcement properties of the stimulus. However, in those studies which have

recorded the pauses following reinforcement and the brief stimulus, a similar effect has been reported to that noted above

Staddon (1970b) states that:

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

The evidence from the above studies showing that, generally, there is a shorter pause following the omission stimulus than following reinforcement, and that the pattern of responding following the omission stimulus is similar to that following reinforcement, is in accord with the view that the reinforcing stimulus has inhibitory after-effects on FR schedules.

Several studies have examined the effects of manipulating the magnitude of the reinforcer on FR schedules (e.g., Hurwitz, Walker, Salmon and Peckham, 1965; Weinstock, White and Bolles, 1965). However, few studies have analysed the effects of changing the reinforcer magnitudes on the after-effects of reinforcement on FR schedules. Lowe et al., (1974) investigated the effects of varying the concentration of a milk reinforcer upon the duration of the post-reinforcement pause, the overall rate of responding and the running rate

produced by an FR 30 schedule. Rats were exposed initially to the FR 30 schedule with a 30% concentration of the milk solution used as the reinforcer. Once the subjects had stabilised with the 30% reinforcer concentration, each subject was presented with concentrations of 10%, 30%, 50%, and 70%. These were presented in a mixed order within each of eight subsequent sessions. The duration of the post-reinforcement pause was found to be a positive function of the concentration of the reinforcer. On the other hand, the running rate, was not systematically related to the magnitude of the preceeding reinforcement except that, at the higher magnitudes running rate tended to decrease. The overall response rate decreased following the greater magnitudes but this reflected the changes observed in the post-reinforcement pause. They concluded that:

"...(the) inhibitory or  $S^{\Delta}$  function of the reinforcing stimulus was enhanced by increasing reinforcement magnitude; decreasing the magnitude had the reverse effect (Lowe et al., 1974, p.559)".

Bitgood and Platt (1973) investigated the effects of different reinforcement durations on pigeons' discrete-trials FR responding, where each reinforcement was followed by a 10-sec T0. Two pigeons were used as subjects and three different durations of hopper access were used as the reinforcers - 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 a discrete trials FR 30 schedule. When the pigeons were placed on a conventional FR 60 schedule it was found that the increasing relationship between running rate and reinforcement duration found in the initial part of the experiment was obtained for only one subject. Also, inspection of their data reveals a tendency for the duration of the post-reinforcement pause to increase as a function of reinforcement duration (cf. Lowe et al., 1974). The anomaly in the results obtained under the discrete-trials and free-operant procedures by Bitgood and Platt (1973) may be related to the contingency used in the former procedure; it is probable that it reduced the likelihood that the after-effects of reinforcement magnitude would be shown.

A study by Powell (1969) lends support to Bitgood and Platt's (1973) discrete-trials FR results. Powell (1969) used two durations of grain access - 2.5 sec and 4-sec - as the reinforcer. He ran pigeons on different FR values, and the reinforcement duration was (a) varied between sessions, and (b) changed within sessions, for each of the subjects. Each reinforcement magnitude condition was accompanied by a different exteroceptive stimulus. Powell (1969) found that the post-reinforcement pause duration was an inverse function of the duration of the reinforcer. Also, only one of the four subjects showed a consistently higher running rate as a function of increasing access to food, while the others showed no

systematic change in running rate. These results are contradictory to those reported by Lowe et al., (1974) and Bitgood and Platt (1973) - using a free-operant procedure - however, in the case of Powell's study it is possible that the differential stimuli associated with the different reinforcer magnitudes may have obscured or attenuated the after-effects of the reinforcing stimulus. For example, Meltzer and Howerton (1973) have 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.

A tentative conclusion that may be drawn regarding the effects of different magnitudes of reinforcement on FR schedule performance is that, in a free-operant situation and in the absence of any added stimuli, the duration of the post-reinforcement pause is positively related to the magnitude of reinforcement. This is consistent with the view expressed by Lowe et al., (1974) that increasing the magnitude of reinforcement enhances the after-effects of the reinforcing stimulus on any particular schedule of reinforcement.

Further, although indirect, evidence of inhibitory control by the reinforcer on FR schedules comes from studies which have shown that there appear to be aversive characteristics related to the FR schedule, particularly during the post-reinforcement pause. For example, Azrin



(1961) and Thompson (1964; 1965) have shown that subjects will respond to produce T0 from FR schedule contingencies and that the amount of time spent in T0 is an increasing function of the FR requirement. Typically, these "escape" responses are restricted to the post-reinforcement pause on the FR schedule. Elicited aggression has also been recorded on FR schedules (e.g., Azrin, Hutchinson and Hake, 1966; Cherek and Pickens, 1970; Flory, 1969b; Gentry, 1968; Hutchinson, Azrin and Hunt, 1968; Knutson, 1970). For example, Azrin et al., (1966) and Knutson (1970) found that pigeons attack rate decreased as a function of increasing time since reinforcement. Similarly, Hutchinson et al., (1968) found that squirrel monkeys on FR food schedules showed biting attack responses during the post-reinforcement pause or early in the ratio run. Also, Gentry (1968) found that pigeons' attack sequences occurred mainly during the post-reinforcement pause on FR schedules. Schedule-induced polydipsia has been found to occur on FR schedules (Falk, 1961) and, again, this occurs mainly during the post-reinforcement pause.

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, delivery of a food pellet as a reinforcer initiated a requirement of 30 responses, i.e., an FR 30 schedule, and



the delivery of a sucrose pellet initiated an FI 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. Following the sucrose reinforcer a long post-reinforcement pause occurred, appropriate to the FI 3-min schedule, whereas following the food pellet there was a shorter post-reinforcement pause, typical of FR 30 performance. Also, when the controlling condition were reversed, i.e., the food pellet initiated the FI schedule and the sucrose pellet the FR schedule requirement, the performances changed accordingly.

The evidence presented in this section is consistent with the notion that the reinforcing stimulus has inhibitory after-effects on FR schedules and the evidence reviewed here suggests that these after-effects develop as a consequence of the temporal relationships between successive reinforcements on FR.

In summary, the evidence reviewed so far suggests that performance on both FI and FR schedules is affected by the temporal distribution of reinforcements. Given this, the question arises whether a similar analysis can be extended to variable reinforcement schedules, i.e., VI and VR schedules, where the temporal relationships between successive

reinforcements are less regular. The remainder of this review is devoted to a description of the performances produced by the various VI and VR schedules and an examination of the evidence regarding the control exerted by the reinforcing stimulus on these schedules.

#### 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). Similarly, Catania (1968) states that:

"...in a variable-interval (VI) schedule, the time that must elapse varies from one reinforcement to the next, and compared with fixed-interval schedules, the rate of responding is relatively constant between reinforcements (p.337)".

A VI schedule is usually specified in terms of the mean interval between reinforcements. However, the same mean interval may be produced by different distributions of intervals. For example, an arithmetic VI schedule is derived from a progression in which successive terms differ by an additive constant (e.g., 10, 20, 30, 40-sec, etc.) while in a geometric VI schedule the intervals are derived from a progression in which successive terms differ by a multiplicative constant (e.g., 5, 10, 20,

40-sec etc.). In another type of VI schedule, random interval (RI), the schedule specifies a recycling time interval at the end of which the first response will be reinforced with a specified probability. For example, on an RI 5-sec schedule, after each 5-sec period of time, the next response is reinforced with a constant probability of, say, 0.1, thus probability of reinforcement does not vary with the number of 5-sec periods since the last reinforcement. In this schedule, the average interval between reinforcements is equal to the recycling time interval divided by the probability of reinforcement; the above example, therefore would be an RI 50-sec schedule i.e.,  $\frac{5}{0.1}$ .

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

"remarkably stable and uniform, and highly resistant to extinction (p.115)".

Given this, VI schedules have been employed extensively as a behavioural baseline for studying the effects of manipulating other variables, Sidman (1960) states that

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

For example, one variable that has been extensively studied in relation to the response rate produced by VI schedules is the rate of reinforcement. These studies may be divided into three main categories; firstly, the effects of varying the rate of reinforcement on the behaviour produced by simple VI schedules. This has been achieved, usually, by varying the mean value of the inter-reinforcement intervals (e.g., Catania and Reynolds, 1968; Clark, 1958) and, generally, it has been reported that response rate is a positive function of increasing rate of reinforcement (i.e., decreasing mean inter-reinforcement interval), although the findings of Catania and Reynolds (1968) suggest that this function is negatively accelerated.

This variable has also been investigated in situations where two or more VI schedules are in some manner presented to a subject either in succession or simultaneously. In one method the VI schedules alternate regularly, with each component schedule accompanied by a differential stimulus. This procedure has been used extensively to study an effect termed behavioural contrast (e.g., Reynolds 1961) and typically involve two phases. In the first phase, identical rates of reinforcement are programmed in

both the VI components, (A and B), i.e., both schedules have the same mean inter-reinforcement interval. In the second phase the schedule of component A is unchanged but rate of reinforcement is reduced in component B. Generally, this is followed by a decrease in the rate of responding in component B and a concomitant increase in the response rate in the unchanged component, A, over and above the previous baseline rate of responding. This effect has been termed positive behavioural contrast (e.g., Rachlin, 1973). Negative behavioural contrast involves a symmetrical experiment. Again, the schedules of components A and B are made equal in the first phase. In the second phase the rate of reinforcement in component B is increased and subsequently the rate of responding in B also increases. In component A, the unchanged component, the rate of responding decreases below the previous baseline level.

In the second method, two or more VI schedules are simultaneously in effect, each associated with a separate response, i.e., a concurrent schedule (Ferster and Skinner, 1957; see also Catania, 1966, for a review of concurrent schedules). Each response operandum and its associated schedule comprise a component. For example, a pigeon may be placed in an experimental chamber with two response keys. Pecking on the left key may produce reinforcement on

VI 1-min schedule and pecking on the right key, reinforcement on a separate VI 30-sec schedule. Because the two schedules run concurrently, the overall rate of reinforcement would be three reinforcements per minute (assuming the pigeon pecked at both keys fairly frequently). In this situation the most common finding is that the relative rate of responding is equal to the relative rate of reinforcement - the relative rate of responding is defined as the rate of responding in one component divided by the sum of the response rates in both components. Similarly, the relative rate of reinforcement is the reinforcement rate in one component divided by the sum of the reinforcement rates in both components. In the above example, this would involve the pigeon responding twice as frequently on the VI 30-sec schedule than on the VI 1-min schedule. This effect has been termed matching, and has been incorporated into various mathematical formulations of the law of effect. (cf. Baum and Rachlin, 1969; Catania, 1963a; Herrnstein, 1961; 1970).

Further examples of the use of VI schedules as a behavioural baseline include; (i) in studying the effects of psychoactive compounds (e.g., Dews, 1958; Ferster and Skinner, 1957), and (ii) in studies of conditioned suppression, where a stimulus associated with, for example, an unavoidable shock is superimposed onto an ongoing VI schedule baseline (e.g., Blackman, 1967).

In general the dependant variable measure used to assess changes in VI performance has been the overall rate of responding: few studies have analysed the pattern of responding produced by the VI schedule. For example, Ferster and Skinner (1957) found that, on an arithmetic VI schedule, the duration of the pause following reinforcement was greatly reduced when several very short inter-reinforcement intervals were included in the schedule. Similarly, Ferster and Skinner also reported that in a VI schedule derived from a geometric progression of intervals, the rate of responding within each interval tended to decline as a function of the time since the preceding reinforcement. It would appear, therefore, that the patterning of responding on a variable-interval schedule is, to some extent, dependant on the manner in which successive reinforcements are programmed. Catania and Reynolds (1968) have pointed out that

"... in a variable-interval (VI) schedule, the first response after a variable elapsed time is reinforced, and a relatively constant rate of responding is maintained throughout each interval. Detailed examination shows, however, that this responding may be modulated by the particular durations of the different intervals that constitute the schedule. In other words, the distribution of responses in time depends upon the distribution of reinforcements in time (p.328)".

There are a number of different VI schedules e.g., arithmetic VI, geometric VI, linear VI, Fibonnacci VI, constant probability VI, and random-interval (RI) schedules, which may be classified in terms of the differing

distributions of reinforcements in time arranged by each VI schedule, and these are related to the particular numerical progression or formula used to generate the desired sequence of inter-reinforcement intervals. The findings of Ferster and Skinner (1957) that the response rate, as a function of time since reinforcement, was affected by the particular distributions of intervals in effect suggests that time since reinforcement per se cannot be the sole determinant of the response rate on VI schedules. Variation in the distribution of reinforcements in time also produces variations in the probabilities of successive reinforcements in time.

In the present context, the probability of reinforcement may be defined as a relative frequency (cf. Catania and Reynolds, 1968) and, for any particular VI schedule, is calculated by dividing the number of times the first response is reinforced after a particular time since reinforcement by the number of opportunities for a reinforcement after that time. For example, consider a VI schedule composed of the following intervals, 0, 20, 20, 60, 120, and 200-sec. The first response following a reinforcement is reinforced in the shortest interval but not in any of the remaining five intervals, therefore, the probability that this response will be reinforced is one sixth (0.17). If this response is reinforced in the 0-sec



interval, the reinforcement terminates the interval and serves as the starting point for another interval. If the response, however, is not reinforced in the 0-sec interval, in the remaining five intervals the probability of reinforcement for subsequent responses becomes zero until the end of the next longer interval. The next opportunity for reinforcement, in the above example, occurs at 20-sec, when two of the remaining five intervals end. Thus, the first response after 20-sec is reinforced on two out of five opportunities or with a probability of 0.40. Similarly, the first response after 60-sec is reinforced with a probability of 0.33, the first response after 120-sec with a probability of 0.50, and the first response after 200-sec with a probability of 1.0.

Catania and Reynolds (1968) have termed this calculation of reinforcement probability, i.e., as a relative frequency of reinforcement, reinforcements per opportunity and have compared it to Anger's (1956) inter-response time per opportunity statistic. Reinforcements per opportunity expresses a conditional probability: the probability that the animal's response will be reinforced, given that the animal has reached a certain time since the last reinforcement.

This treatment of reinforcement probability on VI schedules rests on two assumptions, (i) that the animal cannot discriminate between a given time since reinforcement in one interval and the same time since

reinforcement in an interval of a different duration, and (ii) that the animal responds rapidly enough, when reinforcement becomes available at the end of one interval, to emit the reinforced response before the time at which the next longer interval ends. In the example cited previously, the probabilities of reinforcement for the first response after reinforcement (in the 0-sec interval) and at 20-sec would not be separable if responses never occurred before 25 sec. The relevant probability of reinforcement would be 0.50 for both intervals. However, in most VI schedules, the rate of responding is high enough, relative to the time separating successive opportunities for reinforcement, not to violate this assumption.

One difficulty with this approach is that the probability of reinforcement is calculated for discrete points in time, and is greater than zero only at times since reinforcement when intervals in the schedule end. As Catania and Reynolds (1968) point out

"An account of performance in terms of probability of reinforcement also must deal with other times, when probability is zero. In addition, reinforcements per opportunity is independent of the absolute values on the time scale for an interval schedule (p.340)".

The probabilities would be unaffected, for example, if the values on the time scale in the previous example

were increased or decreased by a constant fraction. Because, presumably, performance would be different after this change (cf. the function relating response rate to mean inter-reinforcement interval, e.g., Clark, 1958), it would appear that probability of reinforcement alone, as defined in this case, is probably not a sufficient determinant of performance, and that the absolute durations of the times separating successive opportunities for reinforcement must be considered in any account of VI schedules. Catania and Reynolds (1968) suggest that this difficulty could be overcome by considering a measure which converted the probabilities of reinforcement at different post-reinforcement times to a local rate of reinforcement at these various times, thus taking into account the absolute durations of the intervals. One necessary assumption for this calculation, however, is that the probability of reinforcement is assumed to be effective over a period of time arbitrarily taken as the time ranging from halfway back to the preceding interval, i.e., the next shortest interval in the sequence, and halfway forward to the next reinforcement, i.e., the next longest interval.

Whatever the particular advantages may be of considering probability of reinforcement in terms of a rate of reinforcement at different times following reinforcement, in the present instance it will be sufficient to consider the differences between the various VI schedules in terms

of the differences in the probabilities of successive reinforcements over time.

The remainder of this section is devoted to a description of the different VI schedules and the patterns of behaviour produced by them. Also, the evidence relating to the after-effects of the reinforcing stimulus on these schedules will be considered.

#### Arithmetic VI schedule

In an arithmetic VI schedule the sequence of intervals is derived from a progression in which successive terms differ by an additive constant (e.g., 10, 20, 30, 40-sec etc.). On an arithmetic VI schedule the probability of reinforcement is relatively low at the early times following reinforcement and gradually increases, with increasing post-reinforcement time, reaching a maximum value of  $p(\text{probability}) = 1.0$  at the end of the longest programmed inter-reinforcement interval. For example, consider an arithmetic VI schedule with the intervals 10, 20, 30, 40 and 50-sec and a mean interval of 30-sec, the probabilities of reinforcement at the termination of these intervals would be 0.20, 0.40, 0.60, 0.80 and 1.0 respectively.

Although the arithmetic VI schedule is the most frequently used VI schedule, few studies have analysed

the pattern of responding produced by this schedule. Catania and Reynolds (1968) analysed the behaviour produced by an arithmetic VI in terms of the overall rate of responding and the local rates of responding. The latter was a measure of the rate of responding at different times following reinforcement. In a VI schedule the overall response rate is constituted from the response rates occurring at different times following reinforcement. Consequently, the early times after reinforcement are 'weighted' more heavily than the later times because, owing to the nature of VI schedules, the early times represent a larger proportion of the total time spent in the schedule. Thus, a consistent change in the local rate of responding early after reinforcement would produce a greater change in the overall rate of responding than the same consistent change later after reinforcement. Also, the overall response rate would tend to obscure, to varying extents, any changes in local response rates.

Catania and Reynolds (1968) exposed pigeons to various values of an arithmetic VI schedule. Overall response rate was found to be an increasing function of the rate of reinforcement (i.e., decreasing mean inter-reinforcement interval). They also found that, for any particular value of the schedule, the local response rate was a negatively accelerated function of the time since reinforcement. When a 0-sec interval was introduced into the distribution

of inter-reinforcement intervals, this resulted in a higher response rate at the early times following reinforcement (cf., Ferster and Skinner, 1957). It would appear, therefore, that pigeons' response rate over time tended to co-vary with the changes in the probability of reinforcement over time.

Kintsch (1965) exposed rats to an arithmetic VI 40-sec schedule and analysed the performance produced by the schedule in terms of the inter-response time (IRT) distribution (including the post-reinforcement pause) and the mean values of successive IRTs following reinforcement, up to the 30th response in any one interval. He found that the IRT distribution tended towards a relatively high frequency of short IRTs, i.e., 0-3-sec; also, following a post-reinforcement pause of approximately 3-4 sec, the duration of the successive IRTs tended to decrease with increasing post-reinforcement time. These findings are similar to those of Catania and Reynolds (1968) and, again, suggest that on VI schedules response rate tends to co-vary with changes in reinforcement probability.

Several studies have examined the effect of manipulating the magnitude of reinforcement upon the performance generated by an arithmetic VI schedule (e.g., Conrad and Sidman, 1956; Davenport, Goodrich and Haquist, 1966; Guttman, 1954; Jenkins and Clayton, 1949;

Schrier, 1965). Although these studies differ on a number of procedural points with regard to the manner in which the different reinforcer magnitudes were presented to the subjects, one general finding has been that the overall rate of responding is positively related to the magnitude of the preceding reinforcement (although the findings of Conrad and Sidman, 1956, suggest that the function is non-monotonic). However, in none of the studies have the effects of changing the magnitude of the reinforcement been analysed with regard to the post-reinforcement pause produced by the schedule.

A recent study, however, by Campbell and Seiden (1974) has investigated the effects of presenting different volumes of a water reinforcer on the duration of the post-reinforcement pause and the response rate of rats exposed to an arithmetic VI 20-sec schedule. The schedule consisted of 3-min periods during which the VI 20-sec was in effect in the presence of one stimulus, alternating with 3-min periods of extinction in the presence of another stimulus, i.e., a mult. VI Ext. schedule. In one experiment the subjects were trained on a single volume of 0.04 ml of water, 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 report that response rate was an increasing function of the magnitude of reinforcement only in the first experiment. The duration of the post-reinforcement pause was directly related to the amount of reinforcement in both of the experiments. The findings of a positive relationship between post-reinforcement pause duration and reinforcer magnitude is similar to that reported for FI schedules (cf. Lowe et al., 1974) and suggests that on an arithmetic VI schedule, as for FI schedules, the reinforcer may acquire inhibitory after-effects.

Further support for this notion comes from studies where some of the scheduled reinforcements have been omitted on an arithmetic VI and a neutral stimulus presented in lieu of reinforcement. Thomas and Blackman (1974) exposed pigeons to a procedure whereby responding on an arithmetic VI 10-sec schedule was reinforced on the basis of an arithmetic VI 66-sec schedule. This procedure resulted in approximately 13% of the VI 10-sec segments ending with reinforcement; all the other non-reinforced VI segments were terminated by either no stimulus (phase 1) or by a change in the key-light colour (phase 2). In both instances there was a shorter pause following non-reinforcement than following reinforcement, also when the



reinforcement omission was signalled (i.e., non-reinforced intervals terminated with a change in key-light colour), the post-omission pause tended to be longer than when the reinforcement omission was unsignalled, although it was still shorter than the post-reinforcement pause. Also, the overall response rate over all the intervals, including those following reinforcement, was greater in the signalled omission phase than in the unsignalled phase. These findings are similar to those reported when reinforcements are omitted on FI schedules (cf., Kello, 1972; Staddon and Innis, 1966; 1969).

De Lorge (1971) exposed pigeons to a multiple second-order schedule; each component of the multiple schedule consisted of an FR5(VI 1-min) schedule and was accompanied by a differential stimulus. On each of the FR5(VI-1min) schedules, at the completion of the non-reinforced VI segments, either (i) no stimulus, (ii) a brief stimulus not paired with food, or (iii) a stimulus paired with food, was presented. This procedure allowed for a within session comparison of the effectiveness of a brief stimulus in maintaining VI responding. De Lorge found that when the brief stimulus that was paired with food was presented in one of the component schedules of the multiple schedule, this maintained a higher running rate (calculated over all the VI segments in a particular component) than when either no stimulus or a non-paired stimulus was scheduled in the other component

of the multiple schedule. Also he reports that:

"The food paired stimulus apparently acquired discriminative properties in the present study. Observation of the birds during the sessions revealed that presentation of the food-paired stimulus frequently was the occasion for the birds to inspect the food aperture. Occurrence of the unpaired stimulus occasioned no observable response other than continued key-pecking (p.24)".

Several studies have shown that when rats responding on an arithmetic VI schedule are given the opportunity to drink water, they will drink large quantities, far in excess of their normal daily water requirement, i.e., they will become polydipsic (e.g., Clark, 1962; Falk, 1961; Stricker and Adair, 1966). Also, the occurrence of this drinking tends to be in the period of time immediately following the presentation of a reinforcer. Similar effects have been reported by Shanab and Peterson (1969) for a single pigeon exposed to a VI 120-sec schedule.

The above evidence provides further, albeit indirect, support for the proposition that the reinforcing stimulus acquires inhibitory after-effects on arithmetic VI schedules.

#### Arithmetic VI schedules with extra short intervals

Catania and Reynolds (1968) compared the performances of pigeons on two arithmetic VI schedules which differed

in that one of the sequences of intervals included a 0-sec interval. They found that adding a 0-sec interval produced a decrease in the duration of the post-reinforcement pause, together with an increase in the response rate during the early period following reinforcement. However, comparison with the arithmetic VI which did not include a 0-sec interval revealed that this elevation in response rate was not sustained, and at later times following reinforcement both schedules produced similar patterns of responding. Ferster and Skinner (1957) also found that the addition of a high frequency of short intervals greatly reduced the pausing after reinforcement and produced a temporary increase in response rate.

Catania and Reynolds (1968) systematically investigated the effects of adding different frequencies of short intervals to an arithmetic VI schedule. They found that at short post-reinforcement times there was a higher rate of responding than at intermediate post-reinforcement times, and that the degree of increase at the short times was related to the frequency of short intervals included in the sequence. At longer post-reinforcement times, in both instances, response rate again increased, usually to a higher level than at other times after reinforcement.

There is no evidence as to the after-effects of the reinforcing stimulus on such schedules, other than the

observation that the duration of the post-reinforcement pause on arithmetic VI schedules is greatly reduced by the inclusion of extra short intervals (Catania and Reynolds, 1968; Ferster and Skinner, 1957).

#### Linear VI schedule

In a linear VI schedule the probability of reinforcement increases monotonically with increasing post-reinforcement time (cf. arithmetic VI). Catania and Reynolds (1968) exposed pigeons to a linear VI schedule and found that the local rate of responding produced by this schedule was similar to that generated by an arithmetic VI, i.e., response rate was a negatively accelerated function of the time since reinforcement. There is no evidence regarding the after-effects of the reinforcer on this VI schedule, however, given the similarity between the pattern of responding generated by this and the arithmetic VI, it is possible that the reinforcer has inhibitory after-effects on a linear VI schedule.

#### Geometric VI and Fibonacci VI schedules

In a geometric VI schedule the intervals are derived from a progression in which successive terms differ by a multiplicative constant (e.g., 5, 10, 20, 40, 80-sec etc.), A Fibonacci VI schedule consists of a sequence of intervals in which the duration of a given interval is

equal to the sum of the durations of the next two shorter intervals as, for example, in an irregular ordering of the following intervals 1, 1, 2, 3, 5, 8, 13, 21-sec etc. (Ferster and Skinner, 1957).

In both of these schedules the probability of reinforcement increases monotonically to a value of 1.0 over successive opportunities for reinforcement. However, examination of the cumulative records presented by Ferster and Skinner (1957) for both of these schedules shows that the local rates of responding decreased as the time since reinforcement increased (cf. an arithmetic VI schedule). Similarly, Chorney (1960) presents results which confirm numerically the trend suggested by Ferster and Skinner's data. The observation that the local rate of responding can decrease even while the probability of reinforcement is increasing provides support for Catania and Reynolds (1968) assertion that something more than simply the probability of reinforcement must be taken in account in analysing the patterns of responding produced by different VI schedules. That is, the times separating successive opportunities for reinforcement as well as the probabilities of reinforcement at these times must be considered in any account of VI schedule performances. Again, there is no evidence regarding the after-effects of the reinforcing stimulus on geometric or Fibonnacci VI schedules.

### Constant Probability VI and Random Interval Schedules

The VI schedule considered so far have arranged for the probability of reinforcement to vary in some systematic manner as a function of the time since the previous reinforcement. Also, it has been shown that the response rate over time tends to vary in a similar manner to the changes in reinforcement probability over time (cf. the arithmetic VI schedule). A constant probability VI schedule, on the other hand, is one with a minimal correlation between probability of reinforcement and the time since reinforcement. That is, a constant probability VI schedule ensures that time since reinforcement cannot acquire discriminative control over responding through its relationship to the availability of subsequent reinforcement. It is possible that this condition may be prerequisite for a local rate of responding that does not change with the passage of time since reinforcement. This condition is obviously not satisfied by an FI schedule, which makes reinforcement available at the same time in every interval; it is also not satisfied by a variety of standard VI schedules, including the arithmetic and geometric VI schedules.

There are two main ways of designing constant probability VI schedules. In one method the separation in time of successive opportunities for reinforcement is held constant while the relative frequencies of different intervals are varied (e.g., Farmer, 1963; Millenson, 1963). The other method holds constant the

relative frequencies of the different intervals while varying the separation in time of successive opportunities for reinforcement (e.g., Catania and Reynolds, 1968; Fleshler and Hoffman, 1962).

The random-interval (RI) schedule used by Farmer (1963) and Millenson (1963) arranged for a constant, recycling time interval  $T$ ; within each  $T$ -sec interval the first response was reinforced with a probability  $p$ . The timing of the  $T$ -sec interval was not interrupted during reinforcement so that a 0-sec interval was possible, if  $T$  was less than the duration of reinforcement. As used by Farmer (1963) the RI schedule also included a limited hold, i.e., a reinforcement which was made available within one  $T$ -sec interval was not kept available beyond the end of that interval. Farmer studied a range of  $T$  values from 0.0062 to 1.0 (when  $p$  corresponded to 1.0 the schedule was equivalent to an FI schedule). He found that the rate of responding was approximately constant at different times since the preceding reinforcement, although this was not the case for all combinations of  $T$  and  $p$  (e.g., when  $T$  was longer and  $p$  equalled 1.0). It is possible that these deviations were caused by either the limited hold, particularly when  $T$  equalled 1-sec, and/or the time to the first opportunity for reinforcement when  $T$  was large (30 or 60-sec), which produced long post-reinforcement pauses.



Millenson (1963) adopted 4-sec as an optimal value of T and varied the value of p from 0.0667 to 0.0183. Generally, the pigeons response rate was approximately constant at various times following reinforcement, although there was some inter-subject variability in this effect.

Catania and Reynolds (1968) exposed pigeons to an RI schedule similar in many respects to those arranged by Farmer (1963) and Millenson (1963). One important difference, however, was that in the series of intervals used by Catania and Reynolds (1968), i.e., the sequence of probabilities of reinforcement at the end of each opportunity for reinforcement was predetermined. They exposed pigeons to a procedure in which the T value of the RI schedule was systematically varied. The probability of reinforcement at the end of each T cycle, on the other hand, was kept constant at a value of  $p = 0.10$ . It was found that following each reinforcement there was a sudden and abrupt transition to a high rate of responding which remained approximately constant until the occurrence of the next reinforcement.

The constant probability VI schedule designed by Fleshler and Hoffman (1962) differs from a RI schedule in that, instead of arranging a fixed recycling time interval (T) between successive opportunities for reinforcement, as the probability of reinforcement increases with the passing of time so also does the time intervals separating the successive opportunities for



reinforcement.

Chorney (1960) exposed pigeons to a constant probability VI schedule and found that the response rate was approximately constant at various times after reinforcement, in a similar manner to the RI schedule. Given that both constant probability VI and RI schedules produce similar patterns of responding, it would appear that the main basis for choosing between them would be in practical terms, e.g., the Flesher and Hoffman (1962) schedule consists of a finite, predetermined sequence of intervals, whereas the RI schedule of Farmer (1963) and Millenson (1963) requires the use of a random generator (note however, the RI schedule used by Catania and Reynolds, 1968, described previously).

Several studies have indicated that the duration of the post-reinforcement pause is a function of the mean inter-reinforcement interval on RI schedules. Lachter (1970), using an RI schedule in which  $p$  was held constant and  $T$  varied from 0-sec to 24-sec, found that the duration of the post-reinforcement pause was an increasing function of the mean inter-reinforcement interval  $(\frac{T}{p})$ . Martin (1971) has shown a similar relationship between the pause after reinforcement and the mean inter-reinforcement interval when  $T$  was held constant at 30-sec and  $p$  varied. Similar effects were reported by Farmer (1963) using a

range of different T and p values, he found that the absolute durations of the post-reinforcement pause increased as the mean inter-reinforcement interval increased. However, the post-reinforcement pause, relative to the mean IRT, decreased as the mean inter-reinforcement interval increased.

It appears, therefore, that on RI schedules, to the extent that the reinforcing stimulus initiates a certain period of non-reinforcement, a pause occurs after reinforcement. For example, on an RI schedule, when  $T = 10\text{-sec}$  the occurrence of reinforcement 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 (Catania and Reynolds reported the occurrence of long post-reinforcement pauses on a constant probability VI when the mean inter-reinforcement interval was 379-sec and the minimum interval approximately 40-sec). If, on the other hand, 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 above evidence, therefore, is consistent with the proposition that the reinforcing stimulus has inhibitory after-effects on RI schedules. Further, albeit indirect, support for the notion comes from a study by Dove, Rashotte and Katz (1974). In common with aggression studies that have been conducted with FI and FR schedules, they found that attack rates of a pigeon on a constant probability VI schedule (derived from the formula of Fleshler and Hoffman, 1962) with food reinforcement, were a function of the mean inter-reinforcement interval. Also these attack responses occurred mainly in the early periods following reinforcement.

Evidence from a study where reinforcements have been omitted on a constant probability VI schedule, however, does not support the notion that the reinforcer has inhibitory after-effects. McMillan (1971) exposed pigeons to a procedure where 50% of the scheduled reinforcements on a constant probability VI 60-sec schedule were omitted in a random manner and with a 'neutral' stimulus (a 4-sec T0 - the same duration as reinforcement) presented in lieu of reinforcement. He found that the duration of the post-omission stimulus pause was greater than the duration of the post-reinforcement pause. This finding is contrary to those reported for FI (e.g., Staddon and Innis, 1966; 1969), FR (McMillan 1971), and arithmetic VI schedules (Thomas and Blackman,

1974) and suggests that the reinforcing stimulus has excitatory and not inhibitory after-effects on the RI schedules.

It is not clear why there should be this discrepancy in the results of the studies which have analysed the after-effects of reinforcement on RI schedules. It may be that it is related to the different methods used to produce the sequences of inter-reinforcement intervals on RI and constant probability VI schedules, i.e., the different methods by which an unchanging probability of reinforcement over time is achieved.

In summary, the literature concerning the patterns of responding produced by various VI schedules reveals that different patterns of responding over time may be maintained by schedules which provide similar overall frequencies or rates of reinforcement. It would appear that the pertinent variable in determining the pattern of responding generated by a given VI schedule is the manner in which the probability of reinforcement varies at different post-reinforcement times. The available evidence regarding the after-effects of the reinforcing stimulus on these VI schedules suggests that, at least for arithmetic VI and constant probability VI schedules, the reinforcer has inhibitory after-effects, (although there is some evidence to the contrary for the latter

schedule, McMillan, 1971). It is possible that the nature, and extent of the after-effects acquired by the reinforcing stimulus are dependent upon two characteristics of any given sequence of inter-reinforcement intervals, namely, (i) the absolute probability of reinforcement at different post-reinforcement times, which is dependent on such factors as the mean inter-reinforcement interval specified by the schedule, and (ii) the relative probabilities of reinforcement at various post-reinforcement times, that is, the probability of reinforcement at any one particular post-reinforcement time relative to the probability at any other post-reinforcement time.

One interesting problem is the extent to which changes over time in the probability of reinforcement on any particular VI schedule determine the nature and extent of the after-effects of the reinforcing stimulus on that schedule. The experiments to be reported in Chapters 4, 5 and 6 were concerned with an analysis of such an interaction.

#### VARIABLE-RATIO

In a variable-ratio (VR) schedule of reinforcement the reinforcement occurs after a given number of responses, the number varying unpredictably from reinforcement to reinforcement (Ferster and Skinner, 1957). A VR schedule

is usually identified in terms of the mean ratio, i.e., the mean number of responses per reinforcement. In most VR schedules successive ratios are usually selected, in irregular order, from a set of ratios described by a particular mathematical progression. For example, an arithmetic VR schedule is derived from a progression in which successive terms differ by an additive constant (e.g., 10, 20, 30, 40 etc.). Similarly, a geometric VR schedule is derived from a progression in which successive terms differ by a multiplicative constant (e.g., 5, 10, 20, 40, 80 etc.). In another type of VR schedule, random ratio (RR), the ratio specifies the probability with which any particular response will be reinforced. For example, in a random ratio 10 schedule, the probability that a given response will be reinforced is  $\frac{1}{10}$  or 0.1, and this probability does not vary with either the number of responses that have been emitted since the last reinforcement or the times separating successive responses.

The VR schedule, as with the VI schedule, is frequently regarded as generating a constant, though high, response rate between reinforcements, with no consistent pause occurring after reinforcement (Nevin, 1973; Staddon, 1972a). A more extreme view is adopted by Hilgard and Bower (1966) who in describing VR schedules state that;

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

Given this, the performance produced by VR schedules has, in general, been considered only in terms of the overall rate of responding. For example, Brandauer (1958) exposed pigeons to a series of RR schedules arranged in order of decreasing probability of reinforcement for each response, i.e., increasing mean ratio requirement, in the range  $p = 1.0$  (CRF) to  $p = 0.00167$ . He found that over a moderate range, overall response rates increased with lower values of  $p$  through a maximum at  $p = 0.02$  for one subject and  $p = 0.01$  for another. Similar effects of increasing the ratio value have been reported by Kelly (1974). Sidley and Schoenfeld (1964) constructed a similar function, using a separate group of pigeons for each  $p$  value. However, they found little relationship between response rates and reinforcement probabilities (ratio values).

A study by Farmer and Schoenfeld (1967) analysed separately the effects of increasing the ratio value on the post-reinforcement pause and running rate. They found that the pause following reinforcement increased as a function of increasing ratio value. Running rate, on the other hand, did not vary systematically as a function of changing ratio requirement. They concluded that on RR schedules:

"These measures (post-reinforcement pause and running rate) do not necessarily co-vary, so that combining them with a single index may mask certain effects of the reinforcement probability variable (p.173)".

Kintsch (1965) analysed rats performance on a VR schedule. He found that on a VR 15 schedule there was a pause of approximately 2-3-sec following reinforcement. This was followed by an abrupt transition to a high rate of responding which remained approximately constant until the occurrence of the next reinforcement.

Farmer and Schoenfeld's (1967) finding of a positive relationship between the mean ratio requirement and the post-reinforcement pause duration raises the question as to the determinants of pause duration on VR schedules. Previously in this chapter evidence has been presented relating to the control by temporal variables of the duration of post-reinforcement pause on FI, FR and VI schedules. A similar analysis may apply to performance of the VR schedule.

The occurrence of reinforcement on VR sets the occasion for a period of non-reinforcement which is at least as long as the time taken by the animal to emit the shortest ratio. In the case of a VR schedule, as opposed to a RR schedule, the reinforcer may also predict a period during which there is a low probability of reinforcement for each response. As the incidence of short ratios is decreased, i.e., when the mean ratio requirement is increased, 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). It is possible, therefore, that the reinforcer on a VR schedule may, by virtue of being a good predictor of non-reinforcement or a period of low reinforcement probability, 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.

The findings of Farmer and Schoenfeld (1967) are consistent with an analysis of RR schedule performance in terms of the temporal control exerted by reinforcement. There is no evidence, however, regarding the after-effects of the reinforcer on VR schedules. The experiments to be reported in Chapter 7 were concerned with this problem.

## CHAPTER 3

### EXPERIMENTAL METHOD

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

#### SUBJECTS.

In all the experiments male hooded rats were used. All the animals were housed individually with ad libitum access to water. A 12 hour day/night cycle was in effect at all

times with the 'day' beginning at 7.00 a.m. and ending at 8.00 p.m. The ambient temperature of the animal house was kept at approximately 20°C.

All animals were weighed daily at approximately the same time.

#### Deprivation:

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

#### APPARATUS:

Two identical operant conditioning boxes were used. The internal dimensions were, floor area 20.0 cm x 24.0 cm and height 18.0 cm. Three of the sides of the box was made of Tufnol lined with sanded aluminium plate, the fourth, a 20.0 cm wide wall, was a metal panel on which the lever, two lights 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 Nestlé's condensed milk in water, was delivered up to the floor of the recess by a motor operated dipper mechanism. The resting position of the dipper was 'up', the reinforcement cycle consisted of the dipper dropping into a container and returning to the resting position.

A lever was mounted 7.0 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, a minimum downward pressure of 15 gms (1.50 Newtons) was required to depress the lever. Two circular lights were also mounted on either side of the panel 3.0 cm from either side wall and 14.0 cm above 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 ceiling of the box consisted of a perspex sheet held in position by two retaining 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 an ambient noise level of  $60 \pm 2$  db.

All auditory stimuli were of a frequency of 1000 Hz and were produced by directing the output from a frequency generator through an amplifier to a 6 in. 15 ohm speaker

located on the inside of the door of the sound attenuating chamber. Whenever used, the intensity of the auditory stimulus was kept constant at  $85 \pm 2$  db. This was measured using a Dawe sound intensity meter with a reference level of 0.0002 dyn/cm at 1000 Hz. All measurements were taken with the meter located approx 6 in. away from the speaker, matching the distance from the speaker to front panel when the chamber door was closed.

In experiments 1, 3 and 5 changing the magnitude of the reinforcer was achieved by having 4 containers mounted on a circular aluminium plate, the centre of which was bolted to the spindle of a 24V AC motor/gearbox. This was located immediately below the dipper recess and changes in the positions of the containers were determined by the operation of the motor via external programming equipment. In experiment 7 another mechanism was used which differed significantly in only one respect, i.e., a circular plastic container divided into 6 separate compartments was used to hold the various milk concentrations. \*

Programming and recording were controlled by solid-state logic units mounted on a bus-bar rack system, operating on a -24V DC current, and housed in a separate room to the experimental boxes. The Variable-Interval and

\* When the reinforcer was omitted only the light and the sound were presented and the dipper did not operate.

Variable-Ratio schedules were programmed using strips of standard 16 mm film punched with holes. Two methods of scheduling reinforcements appropriately were used; (i) a film strip driven at a constant speed, where the punched holes caused a microswitch to close, and (ii) a stepper motor where the punched holes caused the switching of a photocell. The procedure which was used will be indicated for each of the experiments.

Responses and reinforcements were recorded on (i) Gerbrands cumulative recorders (ii) Sodeco electro-mechanical counters and for Experiments 7 and 8, (iii) a Data General Corporation Nova 1200 computer.

#### GENERAL PROCEDURE

All animals were trained to lever press in the conventional manner. Experimental sessions were conducted daily and lasted for, in the case of the Variable-Interval Schedules, 1 hour or 61 reinforcements whichever the shorter. For the Variable-Ratio schedules sessions were terminated after 77 reinforcements. For experiments 1-6 the baseline reinforcer concentration was 40% and for experiments 7 and 8 30%. The reinforcer magnitudes used in experiments 1, 3, 5 and 7 are specified separately for each experiment.

Stability Criteria:

In the experiments reported here all or any appropriate combination of three stability criteria were used. These were:

- (i) Daily visual inspection of the cumulative records
- (ii) Number of sessions of exposure to any one experimental condition
- (iii) Comparison of the response rate on each of 5 consecutive sessions with the mean response rate for the 5 sessions; a deviation of less than 10% either above or below the mean was considered stable.

In each experiment the criteria used to determine stability will be specified.

## CHAPTER 4

### ARITHMETIC VI SCHEDULES OF REINFORCEMENT

In the preceeding chapters it was suggested that as well as having a 'motivating' influence upon behaviour, the reinforcer might also acquire discriminative control over the behaviour immediately following its occurrence, on schedules of reinforcement. For example, according to Ferster and Skinner (1957), on fixed-interval schedules the reinforcer controls a pause because it signals a period in which reinforcement is not available, i.e., it acts as an  $S^{\Delta}$  or inhibitory stimulus. Staddon (1970b;



1972a) has developed this notion into a hypothesis concerning the temporal inhibitory control exerted by the reinforcer on schedules of reinforcement. He states:

"Unless special steps are taken to avoid it, reinforcement is a temporal predictor of nonreinforcement on most reinforcement schedules ..., i.e., reinforcement is usually the stimulus with the lowest relative proximity to the next reinforcement. This is most obviously time on FI; but it may also be the case on VI schedules if the sequence of inter-reinforcement intervals is not truly random in time (Staddon, 1972a; p.223)".

On a fixed-interval schedule, for example, the probability of reinforcement is zero at all times since the last reinforcement, until the end of the interval of time specified by the schedule, after which the probability of reinforcement is  $p=1$ . The reinforcing stimulus, therefore, is the stimulus with the lowest relative proximity to the next reinforcement, and consequently, it acquires temporal inhibitory after-effects. Evidence in support of this notion comes from studies which have demonstrated that the duration of the post-reinforcement pause, on FI schedules, is a linear function of the FI value (Sherman, 1959; Schneider, 1969). Also, it has been shown that the inhibitory after-effects of reinforcement are enhanced when the magnitude of the reinforcer is increased (Jensen and Fallon, 1973; Lowe et al., 1974; Staddon, 1970b). Furthermore, if

some of the scheduled reinforcements are omitted on an FI schedule, and a 'neutral' stimulus is presented in lieu of reinforcement, then there is a shorter pause following the stimulus than following reinforcement (Kello, 1972; Staddon and Innis, 1966; 1969).

Given that the reinforcing stimulus may gain inhibitory control over responding on an FI schedule, the question arises as to whether or not the reinforcer will acquire similar control on variable-interval schedules, especially, as suggested by Staddon (1972a), on a VI schedule where the distribution of inter-reinforcement intervals is not truly random. A VI schedule which meets these requirements is an arithmetic VI schedule.

On an arithmetic VI schedule the inter-reinforcement intervals are arranged according to an arithmetic progression with a specified mean value. Catania and Reynolds (1968) have shown that on an arithmetic VI schedule, the probability of the next reinforcement occurring is relatively low at early times after each reinforcement and then increases, in a positively accelerated manner, until the probability reaches a value of  $p=1$  at the end of the longest possible inter-reinforcement interval, i.e., the longer the time since the last reinforcement the greater the probability of the next one occurring.

Catania and Reynolds found that pigeons exposed to such a schedule adjusted their response rate according to the differences in reinforcement probability at various post-reinforcement times, i.e., rate of responding was a negatively increasing function of time since reinforcement.

It would appear that on an arithmetic VI schedule, in as much as the occurrence of reinforcement predicts a period of low reinforcement probability it is, therefore, the stimulus with the lowest relative proximity to the next reinforcement. The reinforcer should, consequently, acquire inhibitory after-effects on such a schedule.

In the present Chapter two experiments are reported which investigated (i) the effects of manipulating the magnitude of the reinforcer, and (ii) omitting 50% of the scheduled reinforcers, upon the behaviour produced by an arithmetic VI schedule.

## EXPERIMENT 1

### MANIPULATION OF THE MAGNITUDE OF REINFORCEMENT

Guttman (1954) varied the concentrations of sucrose and glucose solutions used as reinforcers on a VI 60-sec

schedule. He used rats in a within-subject design and presented a different concentration on each session. Testing on the 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 the concentration of the sucrose and of the glucose solutions. Goodrich (1965) found similar results using 8% and 32% solutions of sucrose as the reinforcer. He found that the response rate was higher with the 32% solution than with the 8% solution; post-reinforcement pause, on the other hand, was lower at the greater magnitude.

Davenport, Goodrich and Hagguist (1966) using monkeys as subjects, varied the number of pellets of food, given as a reinforcer, on a VI 60-sec schedule. They found that the response rate was an increasing function of the reinforcement magnitude. Conrad and Sidman (1956) ran monkeys on a VI 37-sec schedule. Six different concentrations of a sucrose solution, (0%, 2.3%, 4.0%, 7.5%, 14.0%, 30.0%, and 60.0%) were used, and these were changed on a session by session basis. The overall response rate increased rapidly with increases in the reinforcement magnitude, reaching a peak at about 15-30% reinforcer concentration. They attributed the decline in response rate at the higher concentrations to the effects

of satiation. Schrier (1965) using monkeys as subjects, varied the sucrose solution used as a reinforcer on a VI 30-sec schedule. In addition to this two volumes of sucrose solution were used. With the smaller volume of sucrose solution overall response rate was an increasing function of sucrose concentration. A similar function was found with the larger volume, although there was a tendency for response rate to level off at the higher concentrations for some of the subjects, (cf. Conrad and Sidman, 1956). Another feature of the results was that in all cases there was a tendency for response rate to decline during the course of a session irrespective of the concentration in effect.

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. 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 rates and reinforcement magnitude.

Similar findings, have been reported by Catania (1963b) and by Shettleworth and Nevin (1965), in both cases using

pigeons as subjects and varying the duration of access to grain. Shettleworth and Nevin (1965) conclude that on VI schedules, in a single key situation, pigeons are insensitive to changes in the magnitude of the reinforcer. However, when stimuli are correlated with the different magnitudes it has the effect of making changes in the magnitude of reinforcement qualitatively similar to changes in the frequency of reinforcement - increases in the frequency of reinforcement have been shown to be accompanied by increases in the rate of responding (Catania and Reynolds, 1968; Clark, 1958). This conclusion is further supported by the findings of Keeseey and Kling (1961). In one of their experiments they used a procedure in which the amount of the reinforcer 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. Evidence from studies in which two VI schedules are concurrently available, and which have a different magnitude associated with each schedule do not, generally, support this position, e.g., Fantino, Squires, Delbrück and Peterson (1973). This is further complicated by differences in the response measures which are used, i.e., relative response rate in

concurrent schedule studies as opposed to absolute rate in single schedule studies. As Lowe (1974) points out, the main conclusion to be drawn from the literature on concurrent schedules is that when one or more magnitudes are available to an animal, then the magnitude variable is an effective determinant of choice behaviour. Animals prefer greater magnitude of reinforcement.

In all the studies considered so far, with the exception of that of Goodrich (1965), the dependent variable measure employed was overall response rate. However, one recent study by Campbell and Seiden (1974) has investigated the effects of changing the reinforcer magnitude on the duration of the post-reinforcement pause and the response rate. Campbell and Seiden (1974) investigated the effects on different volumes of water reinforcer on rats' responding on a Mult. VI 20-sec Extinction schedule. The schedule consisted of 3-min periods during which the VI schedule was in effect, in the presence of 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. Response rate was an increasing function of reinforcement magnitude only in the first experiment. The duration of the post-reinforcement pause, on the other hand, was directly related to amount of reinforcement in both experiments. These data suggest that the experimental design used to test the effects of different magnitudes 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, i.e., within sessions or on successive sessions, than when no such temporal contrast occurs, i.e., in studies using a between-subject design.

In the present experiment different concentrations of a milk reinforcer were presented in a within-subject and within-session design. The VI schedule studied consisted of an arithmetic series of 15 intervals ranging from zero to twice the mean value of the schedule, and arranged in irregular order (cf. Catania and Reynolds, 1968). Lowe et al., (1974) have pointed out that much of the divergence in the results of previous studies in which the magnitude of reinforcement is varied, is probably due to the 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 changes in the magnitude of reinforcement, and when they are averaged, the extent of the changes in the two may be masked. For this reason, in the present experiment, the overall rates, running rates, post-reinforcement pauses and local rates related to the different magnitudes were considered separately.

## METHOD

### Subjects

Three male hooded rats served as subjects (12, 13, 22). They were housed individually and had ad lib. access to water in the home cages. They were maintained at approximately 80% of their free-feeding weights throughout the experiment.

### Apparatus

The basic apparatus has been described in Chapter 3. In the present experiment the arithmetic VI was scheduled using a device that advanced a loop of punched tape a constant distance with each operation. This was stepped by an electronic timer, with the intervals between reinforcements determined

by the spacing of the holes punched in the tape. Thus the absolute durations of the intervals depended on the rate at which the timer operated the programmer, but the relative durations were independent of the timer.

The punched holes in the tape provided a series of 15 intervals from an arithmetic progression in the following order: 14, 8, 6, 5, 9, 2, 13, 7, 1, 12, 4, 10, 0, 3. The numbers indicate the durations of the intervals between successive reinforcements in multiples of  $t$  seconds, the setting of the electronic timer. In the present experiment the average interval of the VI schedule was  $7t$  sec; with  $t$  equal to 8.5 sec, giving an average inter-reinforcement interval of 59.5 sec.

At the end of each interval when a response was to be reinforced, the controlling apparatus stopped until the next response occurred; the next interval began only after the delivery of reinforcement. Thus a distribution of minimum inter-reinforcement intervals was arranged. In practice, owing to a fairly high rate of responding, this did not differ significantly from the actual inter-reinforcement intervals.

Local response rates were collected on a series of digital counters which stepped up one with each step of

the interval programmer and reset after each reinforcement. In this way responses were distributed to any one of 14 counters, which represented successive periods of time after reinforcement. The time represented by each counter was  $t$  sec, and each counter recorded responses only within inter-reinforcement intervals equal to or longer than the time after reinforcement that the counter represented. For example, the first counter cumulated responses that occurred during the first  $t$  sec of all intervals except of 0-sec interval. Correspondingly, the seventh counter cumulated responses during the seventh  $t$  sec of only those intervals  $7t$  sec long or longer. The fourteenth counter cumulated responses only during the fourteenth  $t$  sec of the  $14t$ -sec interval, the longest interval in the series. Thus, response rates at early times after reinforcement were based on larger samples of responding than response rates at later times.

### Procedure

#### Training

First the subjects were lever trained, and after this they were immediately placed on the VI 60-sec schedule. The reinforcer was a 40% solution of Nestlé's condensed milk in water. The subjects were run daily

until their mean daily response rate over 5 successive sessions did not differ by more than  $\pm 10\%$  of the mean of the 5 days. The numbers of sessions conducted were 74, 66, and 88 for Subjects 12, 13, and 22 respectively. The first response in each session was reinforced and the VI schedule then operated; beginning at a different place in the series of intervals in successive sessions. Sessions ended after each interval in the series had occurred four times (61 reinforcements). The duration of each session was approximately one hour.

#### Testing

The same schedule was in effect as in training. Four different reinforcer concentrations 0% (Water), 20%, 40% and 60% were presented in blocks of 5 reinforcements; the order of the blocks was random with the constraint that, in each session, each block occurred 3 times. Three test sessions were conducted each consisting of 60 reinforcements. After this the subjects were returned to the baseline conditions.

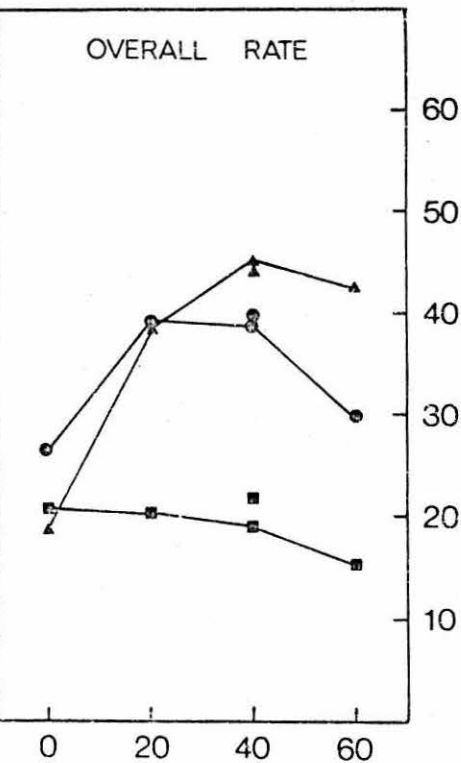
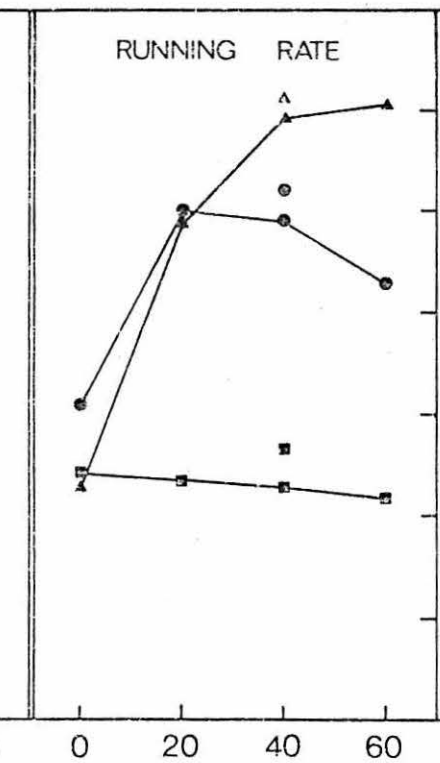
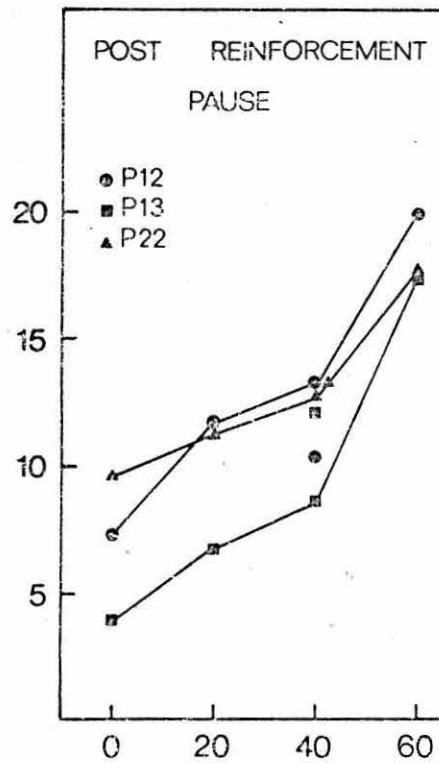
## RESULTS

Figure 1 (left hand panel) shows that for all subjects the median duration of the post-reinforcement pause increased as a function of the concentration of the preceding reinforcer, (see Table 1 for the interquartile ranges). The mean duration of the post-reinforcement pause as a function of ordinal position within a test block is shown in Table 2; the duration of the post-reinforcement pause changed appropriately after a new concentration was presented in a block. One exception to this occurred on the 0% concentration for Subject 22, where the mean post-reinforcement pauses were very much larger than those of Subjects 12 and 13. This was a consequence of a few very long pauses after the 0% concentration for Subject 22.

The centre panel of Figure 1 shows the effects of reinforcement magnitude upon mean running response rate (i.e., the rate calculated by taking into account only the time from the first response in each interval to the next reinforcement). There was little consistency between the subjects in this respect; the running rate for Subject 12 increased markedly from the 0% to 20% concentrations but declined at the 40% and 60% concentrations; for Subject 22 it increased at the 20% and 40% concentrations but declined at 60%; for Subject 13 the running rate

Figure 1. The median post-reinforcement pause (left panel), the mean running rate (centre panel), and the mean overall rate (right panel) as functions of the preceeding reinforcer magntiude. The unconnected points represent the baseline data. For each subject data were taken from the last three baseline sessions and the three test sessions.

TIME IN SECONDS



RESPONSES PER MINUTE

CONCENTRATION (%)

TABLE 1

The interquartile ranges of the post-reinforcement pause durations as a function of the preceding reinforcer concentration. Data are from the last three baseline sessions and the three test sessions.

ANIMAL	CONCENTRATION	POST-REINFORCEMENT PAUSE IN SECONDS	
		BASELINE	TEST
12	0%	5.1 - 16.3	4.0 - 10.5
	20%		8.8 - 14.1
	40%		10.9 - 16.1
	60%		13.5 - 25.7
13	0%	5.9 - 16.9	1.9 - 6.8
	20%		5.7 - 8.3
	40%		6.7 - 11.0
	60%		13.1 - 22.3
22	0%	11.0 - 18.6	2.8 - 18.4
	20%		8.3 - 13.5
	40%		11.1 - 14.0
	60%		15.2 - 20.6



TABLE 2

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
0%	12	9.7	8.6	5.9	6.9	12.3
	13	6.0	5.7	2.7	4.6	7.9
	22	11.7	18.4	14.1	15.7	6.8
	MEAN	9.1	10.9	7.6	8.5	9.0
20%	12	12.3	10.9	12.9	9.8	11.3
	13	10.2	6.9	5.8	6.7	9.7
	22	12.2	10.7	11.1	11.1	11.7
	MEAN	11.6	9.5	9.9	8.3	10.9
40%	12	14.4	13.2	13.1	14.2	15.4
	13	9.8	8.9	10.0	8.2	12.0
	22	12.0	11.3	12.5	12.1	14.4
	MEAN	12.1	11.1	11.9	11.5	13.9
60%	12	19.2	18.9	18.7	18.5	21.8
	13	12.3	19.6	18.5	18.3	22.5
	22	16.0	16.9	18.1	18.5	21.4
	MEAN	15.8	18.5	18.4	18.4	21.9

decreased slightly from 0% to 60% concentrations. Similar effects were observed for the overall rates of responding (right hand panel of Figure 1).

Figures 2, 3 and 4 show the mean local rates of responding for the last three baseline and the three magnitude sessions for Subjects 12, 13 and 22 respectively. Generally, local response rate was a negatively accelerating function of the time that had elapsed since the last reinforcement. There are two features of the local response rates that merit particular attention. Firstly, at early times after reinforcement the relationship between reinforcer concentration and response rate tended to be inverse. As the local rates were calculated inclusive of the post-reinforcement pause, however, this finding is consistent with the positive relationship between post-reinforcement pause duration and reinforcer magnitude shown in Figure 1. Secondly, there was a lower local response rate after the 0% concentration for Subjects 12 and 22. However, Subject 13 showed no systematic difference between the local rates following the different concentrations. This finding is consistent with the running rate data reported in Figure 1.

(note: the differences in the duration of the post-reinforcement pause related to the concentration of the reinforcer cannot be attributed to any difference in licking-time as observations by the present author and by Lowe, 1974, indicate that with any concentration the time spent near the dipper rarely exceeded 3-sec).

Figure 2. The rates of responding following the different reinforcer magnitudes as functions of the time since reinforcement on an arithmetic VI 60-sec schedule for subject P12. Data are averages of the last three baseline sessions (B) and the three test sessions.

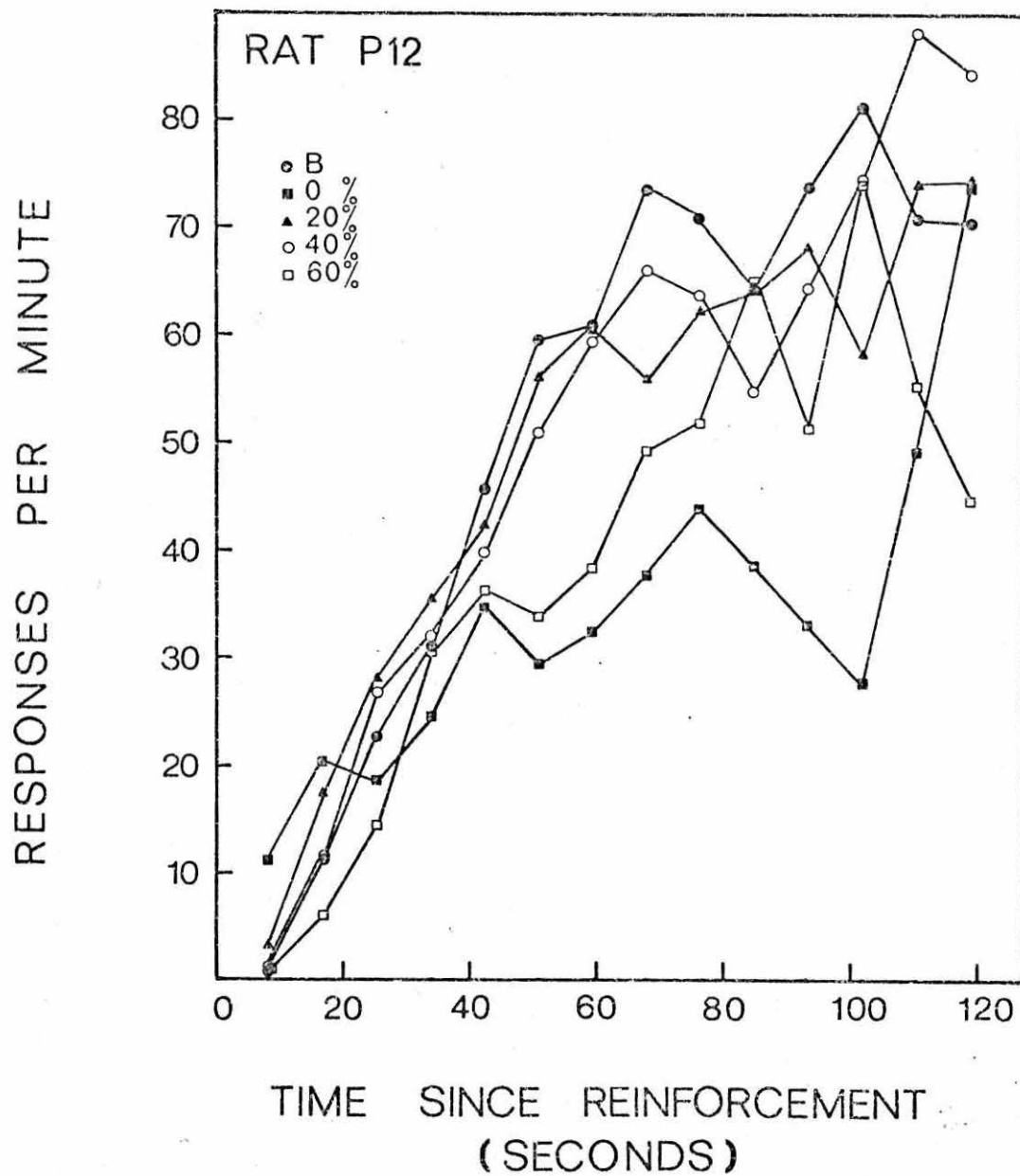


Figure 3. The rates of responding following the different reinforcer magnitudes as functions of the time since reinforcement on an arithmetic VI 60-sec schedule for subject P13. Data are averages of the last three baseline sessions (B) and the three test sessions.

RESPONSES PER MINUTE

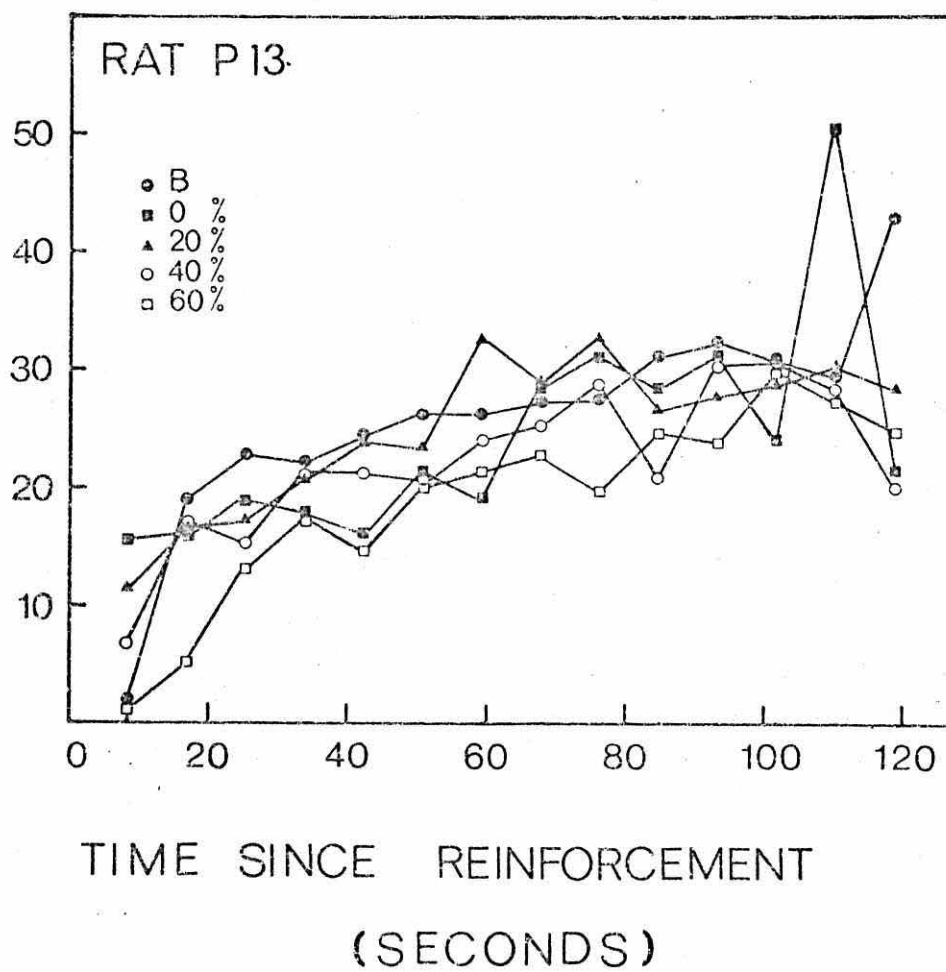
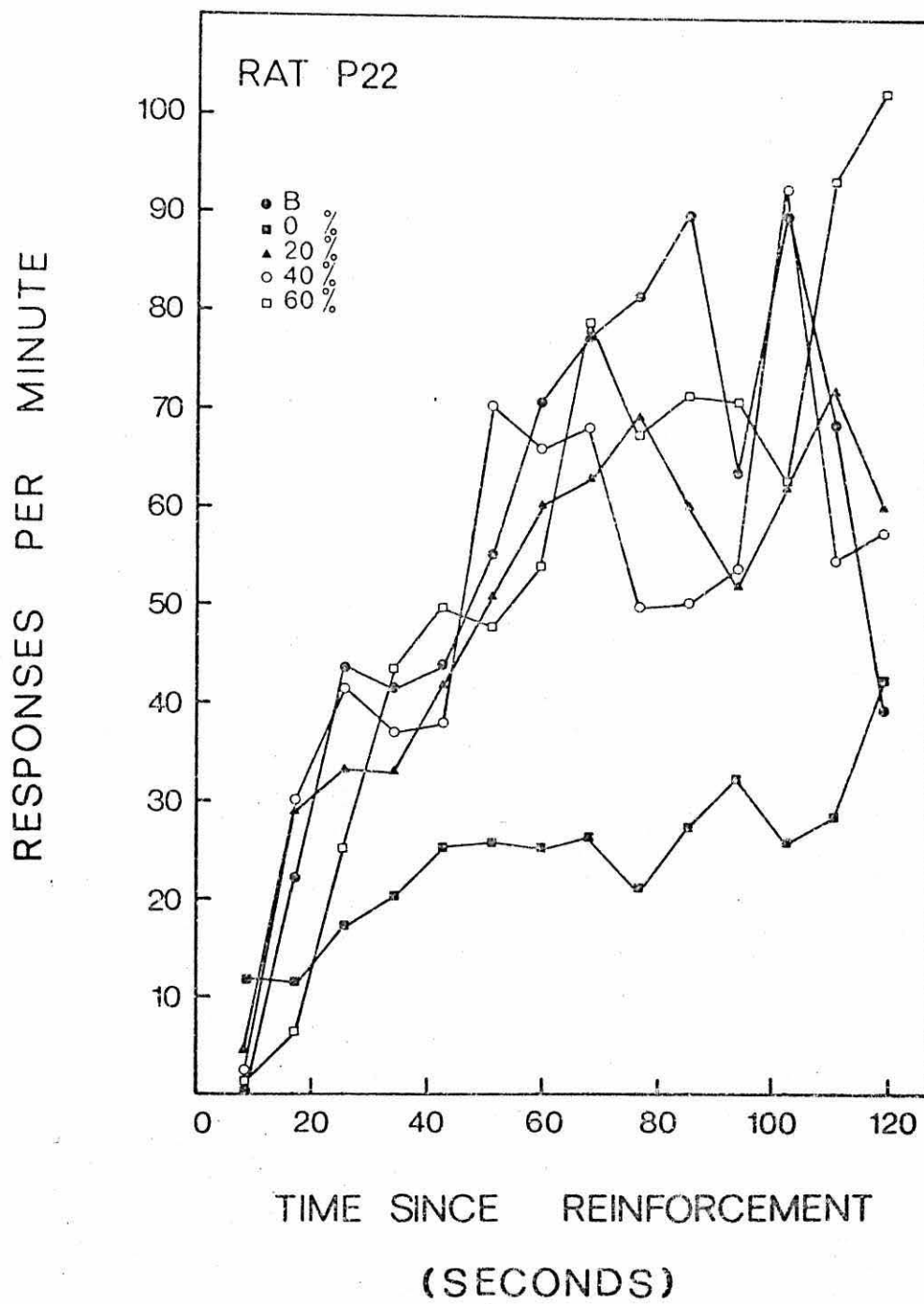


Figure 4. The rates of responding following the different reinforcer magnitudes as functions of the time since reinforcement on an arithmetic VI 60-sec schedule for subject P22. Data are averages of the last three baseline sessions (B) and the three test sessions.





## EXPERIMENT 2

### THE OMISSION OF REINFORCEMENT

As Staddon (1972a) has suggested, one way to investigate the temporal controlling properties of reinforcement is by using the reinforcement omission procedure. In this procedure, on some of the occasions when a reinforcement is due, a 'neutral' stimulus is presented in lieu of the reinforcement. On an FI schedule, for example, each interval ends in either reinforcement or non-reinforcement with certain specified probabilities (if reinforcement is omitted on a truly random basis, the probability of each interval ending in reinforcement would be  $p=0.5$ ). Staddon (1970b) has also argued that,

"the effects of reinforcement omission in a given situation depend entirely upon the after-effects of reinforcement in that situation. The effects on subsequent responding of a stimulus presented in lieu of reinforcement (*i.e.*, nonreward) will be of the same kind as the effects of reinforcement, but generally of a smaller magnitude. (Staddon, 1970b , p.230)".

Taking again the example of an FI schedule, several studies have shown that a 'neutral' stimulus presented in lieu of reinforcement can acquire inhibitory after-effects when, as with reinforcement, it is a predictor of non-reinforcement (Kello, 1972; Staddon and Innis, 1966; 1969).

Generally, it has been found on FI schedules that, with this procedure, there is a higher response rate after non-reinforcement than after reinforcement; this has been reported with rats (Jensen and Fallon, 1973; Zimmerman, 1971), and pigeons (Kello, 1972; Zeiler, 1972). However, it has been shown that these differences in rate following non-reinforcement and reinforcement are primarily due to a shortening of the post omission pause in comparison to the duration of the post-reinforcement pause (Kello, 1972; Staddon and Innis, 1966; 1969). Similar effects on the pauses following reinforcement and non-reinforcement have been reported on schedules such as, e.g., FR (McMillan, 1971), VR (Chapter 7) and VI (Thomas and Blackman, 1974).

Thomas and Blackman (1974) investigated the effects of omitting some of the scheduled reinforcements on an arithmetic VI schedule. They exposed pigeons to a procedure where responding on an arithmetic VI 10-sec schedule was reinforced according to an arithmetic VI 66-sec schedule (the schedule was a VI 66-sec (VI 10-sec) second-order schedule). This procedure resulted in approximately 13% of the VI 10-sec segments ending with reinforcement; all the other VI segments were terminated by either no stimulus (phase 1) or by a change in key light colour (phase 2). The former phase was in

effect for 13 sessions and the latter for 37 sessions. In all instances, there was a shorter pause following non-reinforcement than following reinforcement. However, when the reinforcement omission was signalled, the post omission pause tended to be longer than when the omission was unsignalled. Also, the overall response rate over all the intervals, including those following reinforcement, was greater in the signalled omission phase than in the unsignalled phase.

In the present experiment the effects of omitting 50% of the scheduled reinforcements on the behaviour produced by a simple arithmetic VI schedule were investigated; the pauses, overall rates, running rates, and local response rates following reinforcement and following the omission stimuli were analysed separately.

## METHOD

### Subjects

Three male hooded rats (12, 13, and 22) with experience on an arithmetic VI schedule, served as subjects. They were housed and maintained as before.

### Apparatus

The apparatus, stimuli, scheduling and recording equipment was the same as used in Experiment 1. The tone

stimulus (with a frequency of 1000 Hz) was produced by directing the output of a frequency generator through an amplifier, to a 6-inch 15 ohm speaker located on the lid of the experimental box. The intensity of the tone was 85 db. The light stimulus was produced by 2 x 12 Watt 24VD.C. bulbs located on the front panel of the experimental box.

#### Procedure

The subjects were placed on an arithmetic VI 60-sec schedule with each reinforcement accompanied by a 0.5-sec light/tone stimulus. The concentration of the milk reinforcer was held at 40% throughout the experiment; all sessions were terminated after 61 reinforcements, (cf. Experiment 1). The subjects were exposed to the schedule for a minimum of 25 sessions after which the same stability criterion as used in Experiment 1 was in effect. When responding was stable (this was after 33, 34, and 36 sessions for the three subjects respectively), the subjects were exposed to a procedure whereby 50% of the scheduled reinforcements were randomly omitted, thus producing either reinforcement plus light/tone stimuli or light/tone stimuli alone at the end of each completed interval. The reinforcement omission procedure was in effect for three sessions after which the subjects were returned to the arithmetic VI 60-sec schedule with 100% reinforcement.

## RESULTS

Figures 5, 6 and 7 show the mean durations of the pauses (upper panels) and the running rates (lower panels) following reinforcement and following the omission stimuli for Subjects 12, 13 and 22 respectively. The data are from the last five baseline sessions, the three reinforcement omission sessions and the first five return-to-baseline sessions. In all instances the duration of the pause following the omission stimuli was considerably less than the duration of the post-reinforcement pause. For Subject 12 the duration of post-reinforcement pause in the first two omission sessions decreased in comparison to the duration of the post-reinforcement pause in the baseline sessions. However, there was a subsequent increase in the third omission session. The duration of the post-stimuli pause decreased slightly over the three omission sessions. A similar effect on the duration of the post-reinforcement pauses was observed for Subject 13, although the increase was not as great in the third omission session as for Subject 12; the duration of the post stimulus pause increased in the second omission session but decreased again in the third session. For Subject 22 there was a decrease in post-reinforcement pause duration in the first omission session, followed by an increase over the remaining sessions; there was little difference between the post stimuli pauses over the three sessions. For all the

Figure 5. The upper pannel shows the mean durations of the post-reinforcement pause (filled circles) and the post omission stimuli pause (filled squares). The lower panel shows the running rates following reinforcement (filled circles) and following the omission stimuli (filled squares). The unconnected points represent the means of the baseline and return-to-baseline sessions. Data are from the last five baseline sessions (30-34) the three reinforcement omission sessions (35-37) and the first five return-to-baseline sessions (38-42) for Subject P12.

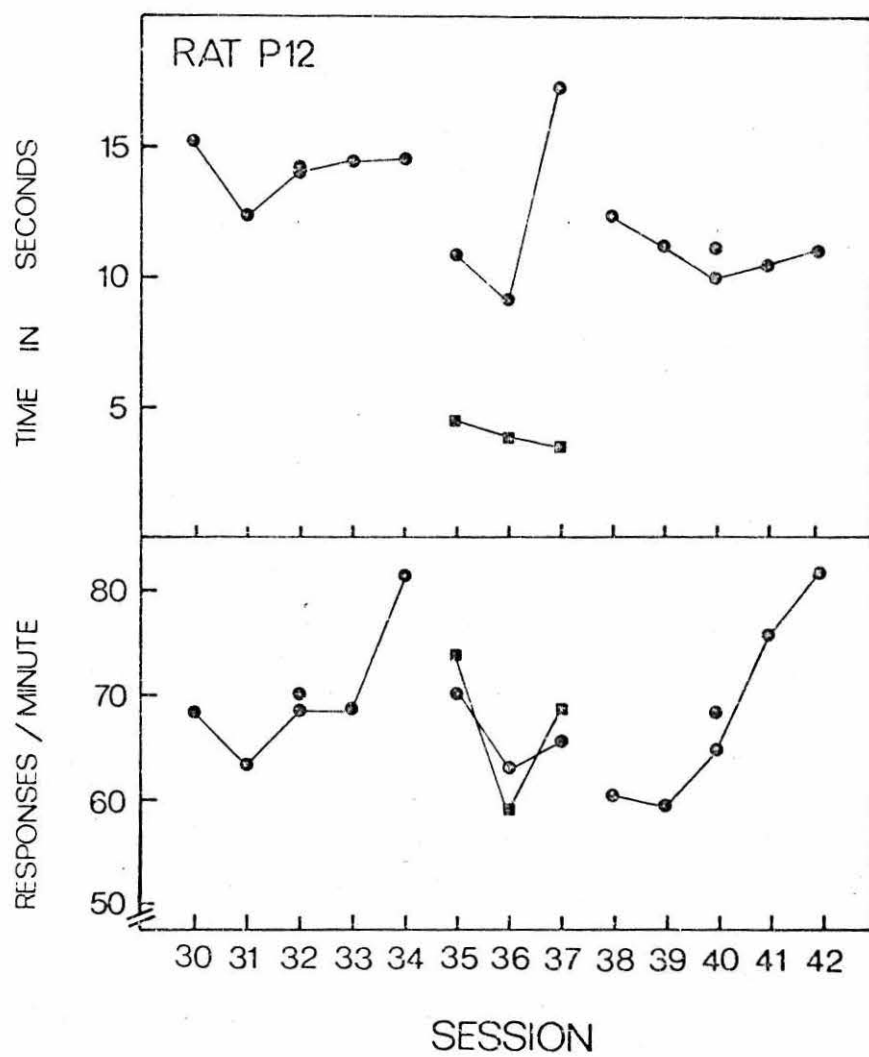


Figure 6. The upper panel shows the mean durations of the post-reinforcement pause (filled circles) and the post-omission stimuli pause (filled squares). The lower panel shows the running rates following reinforcement (filled circles) and following the omission stimuli (filled squares). The unconnected points represent the means of the baseline and return-to-baseline sessions. Data are from the last five baseline sessions (29-33), the three reinforcement omission sessions (34-36), and the first five return-to-baseline sessions (37-41) for Subject P13.



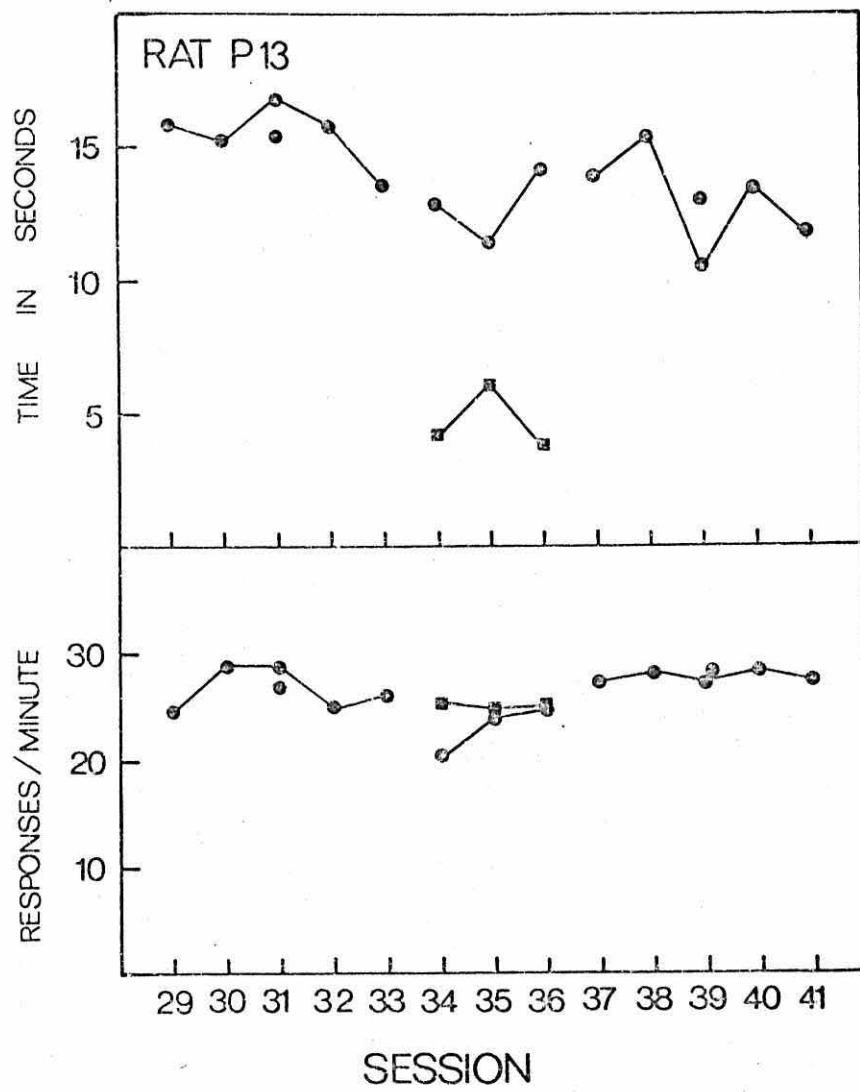
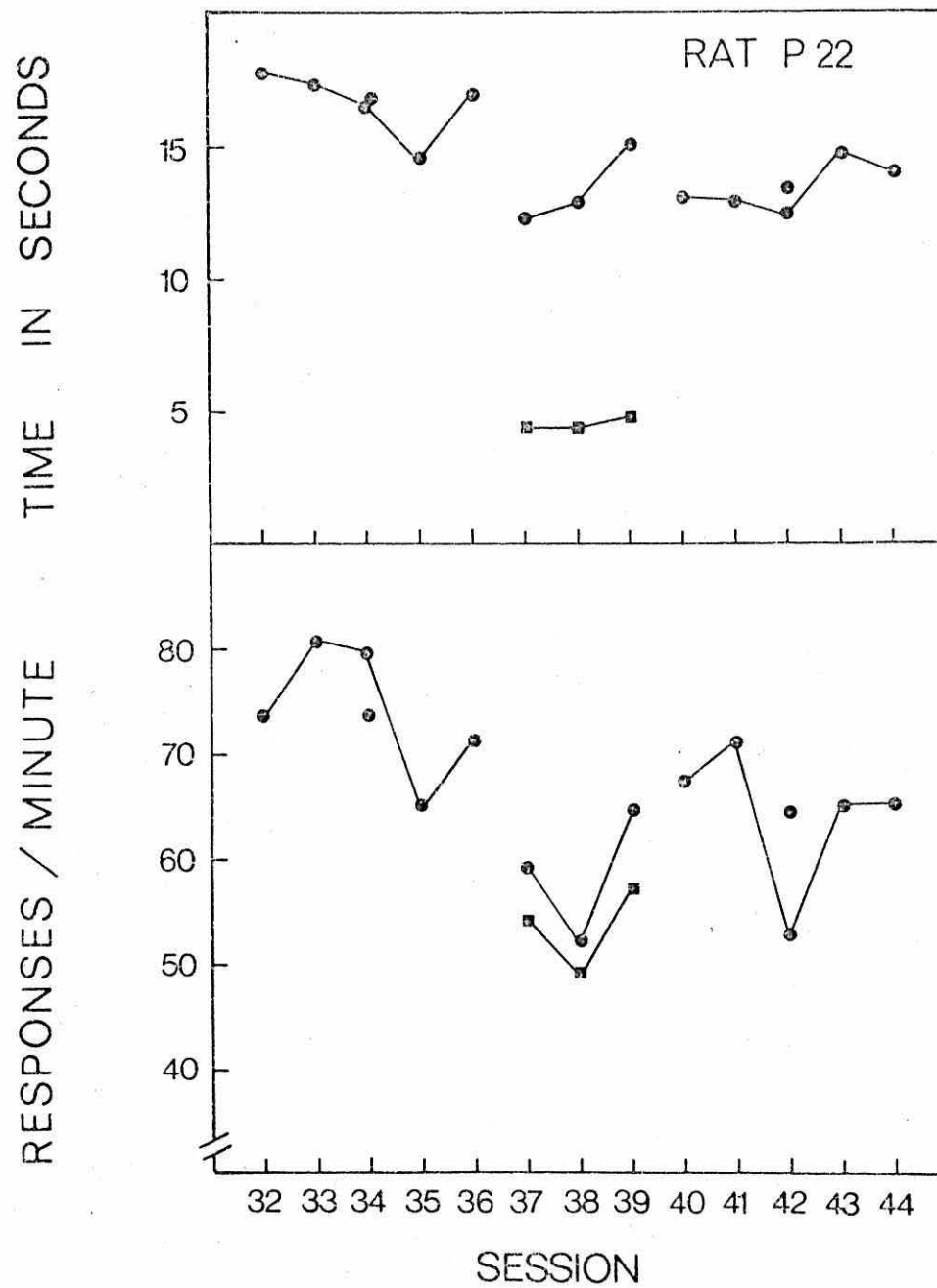


Figure 7. The upper panel shows the mean durations of the post-reinforcement pause (filled circles) and the post omission stimuli pause (filled squares). The lower panel shows the running rates following reinforcement (filled circles) and following the omission stimuli (filled squares). The unconnected points represent the means of the baseline and return-to-baseline sessions. Data are from the last five baseline sessions (32-36), the three reinforcement omission sessions (37-39) and the first five return-to-baseline sessions (40-44) for Subject P22.



subjects the mean post-reinforcement pause for the first five return-to-baseline sessions was lower than the mean post-reinforcement pause over the last five baseline sessions.

There was little consistent difference between the running rates following reinforcement and following the omission stimuli; the running rate following reinforcement was lower than the rate following the omission stimuli on two of the omission sessions for Subject 12. This was also the case for the three omission sessions for Subject 13 (although the magnitude of the difference was small on the second and third sessions); for Subject 22 the running rate following the omission stimuli was consistently lower than the rate following reinforcement. For Subject 12 there was considerable difference between the running rates on the baseline session and the return-to-baseline sessions, although there was little difference between the means of these sessions; for Subject 13 there was little difference between the running rates on the baseline and return-to-baseline sessions; for Subject 22 there was a tendency for running rate to decline in the return-to-baseline sessions compared to the baseline sessions. It was also found that for Subject 22, and to some extent for Subject 12, the running rates after reinforcement and after the omission stimuli both decreased during the omission sessions. Table 3 shows the mean overall rates for the baseline, omission and return-to-baseline

TABLE 3

Mean overall rates of responding. Data are from the last five baseline sessions, the three reinforcement omission sessions and the first five return-to-baseline sessions.

ANIMAL	<div> <div>BASELINE</div> <div>OMISSION</div> <div>RETURN-TO-</div> <div>BASELINE</div> </div>			
	FOLLOWING:			
	REINFORCEMENT STIMULI			
12	54.1	53.0	62.5	56.0
13	20.2	18.3	22.8	21.8
22	53.1	44.3	49.0	49.4

sessions. In all instances, during the reinforcement omission sessions, the overall rate was higher after the omission stimuli than after reinforcement. This was due principally, as shown in Figures 5, 6 and 7, to a reduction in the pausing following the omission stimuli compared to the post-reinforcement pause.

Figures 8, 9 and 10 show the mean local response rates following reinforcement and following the omission stimuli for the last three baseline sessions and the three reinforcement omission sessions. Response rate for Subjects 12 and 13 was a negatively accelerating function of time since reinforcement (cf. Experiment 1); for Subject 22, however, this function tended to be linear. Local response rate following the omission stimuli was, for Subjects 12 and 13, higher than the rate following reinforcement, during those inter-reinforcement intervals of up to approximately 6t seconds in duration or longer (see Method, Experiment 1), i.e., there was a higher response rate initially, in the intervals following the omission stimuli than in the intervals following reinforcement. After this time there was little difference in the local rates following reinforcement and following the omission stimuli. Although the local response rates were calculated inclusive of the post-reinforcement and post-stimuli pauses, this cannot to any great extent account for the differences found between the local rates at the early times in each interval. The same effect was observed

Figure 8. The rates of responding as functions of the time since reinforcement on the baseline (filled circles) and the reinforcement omission sessions (filled squares), also, the rate of responding as a function of the time since the omission stimuli (filled triangles) for Subject P12. Data are averages of the last three baseline sessions and the three reinforcement omission sessions.

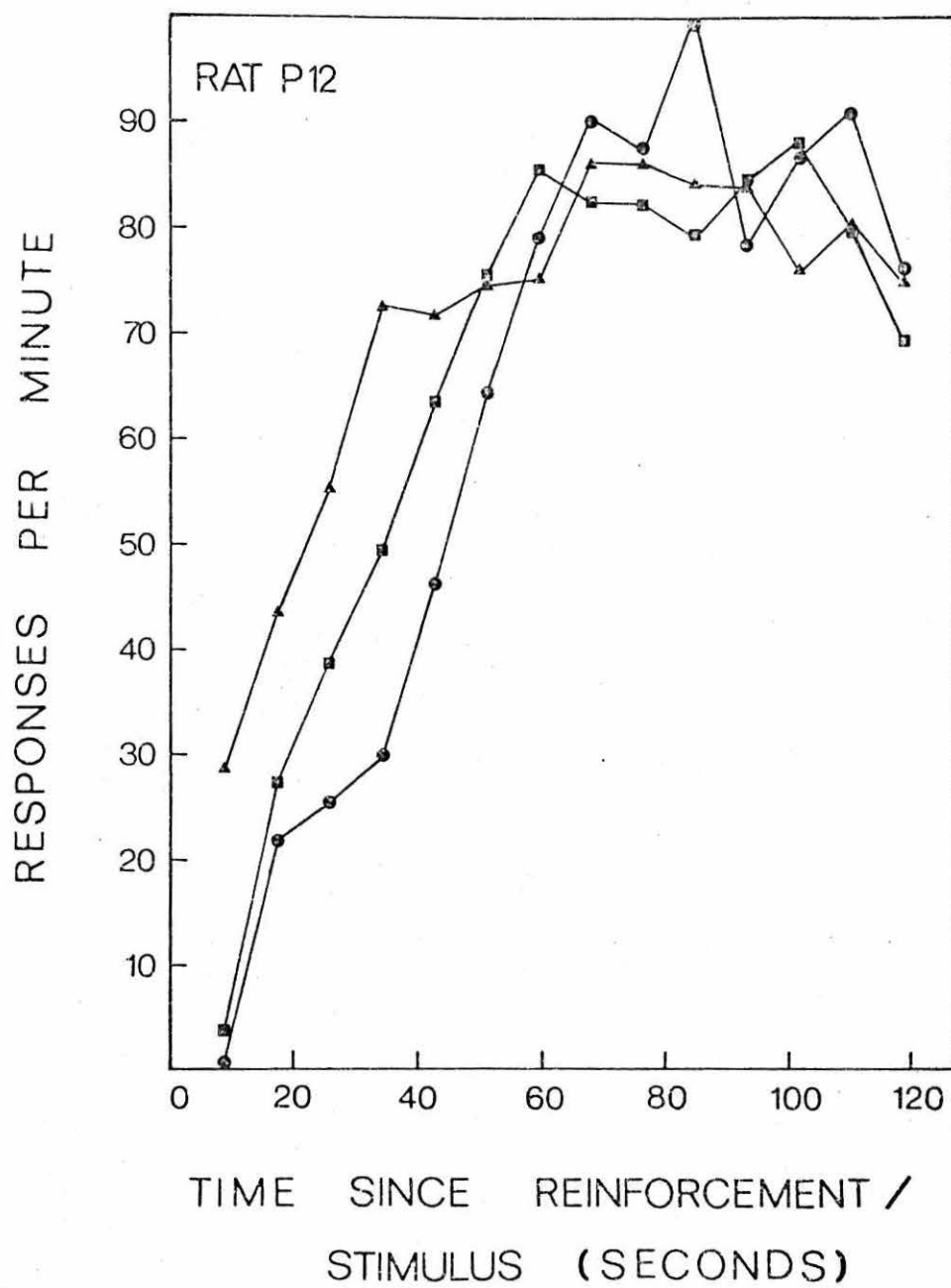
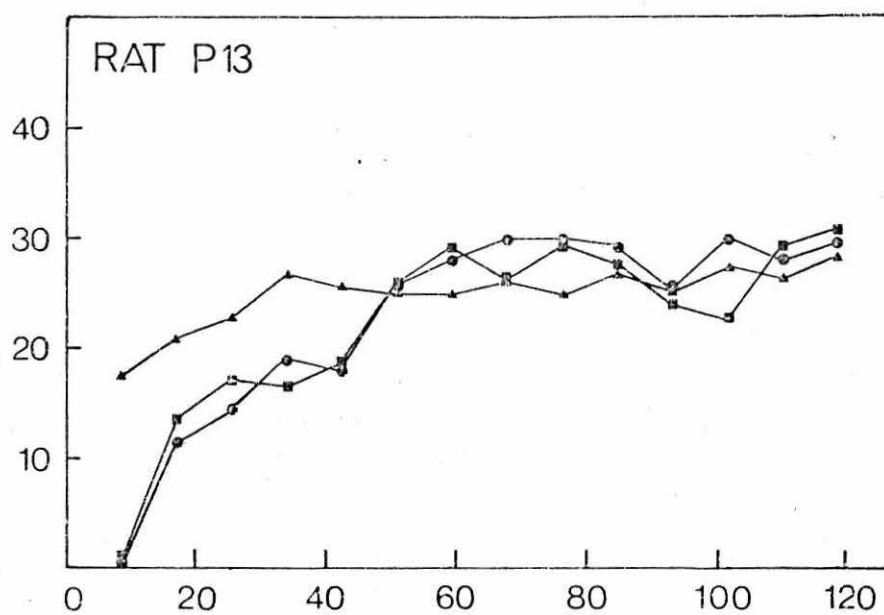




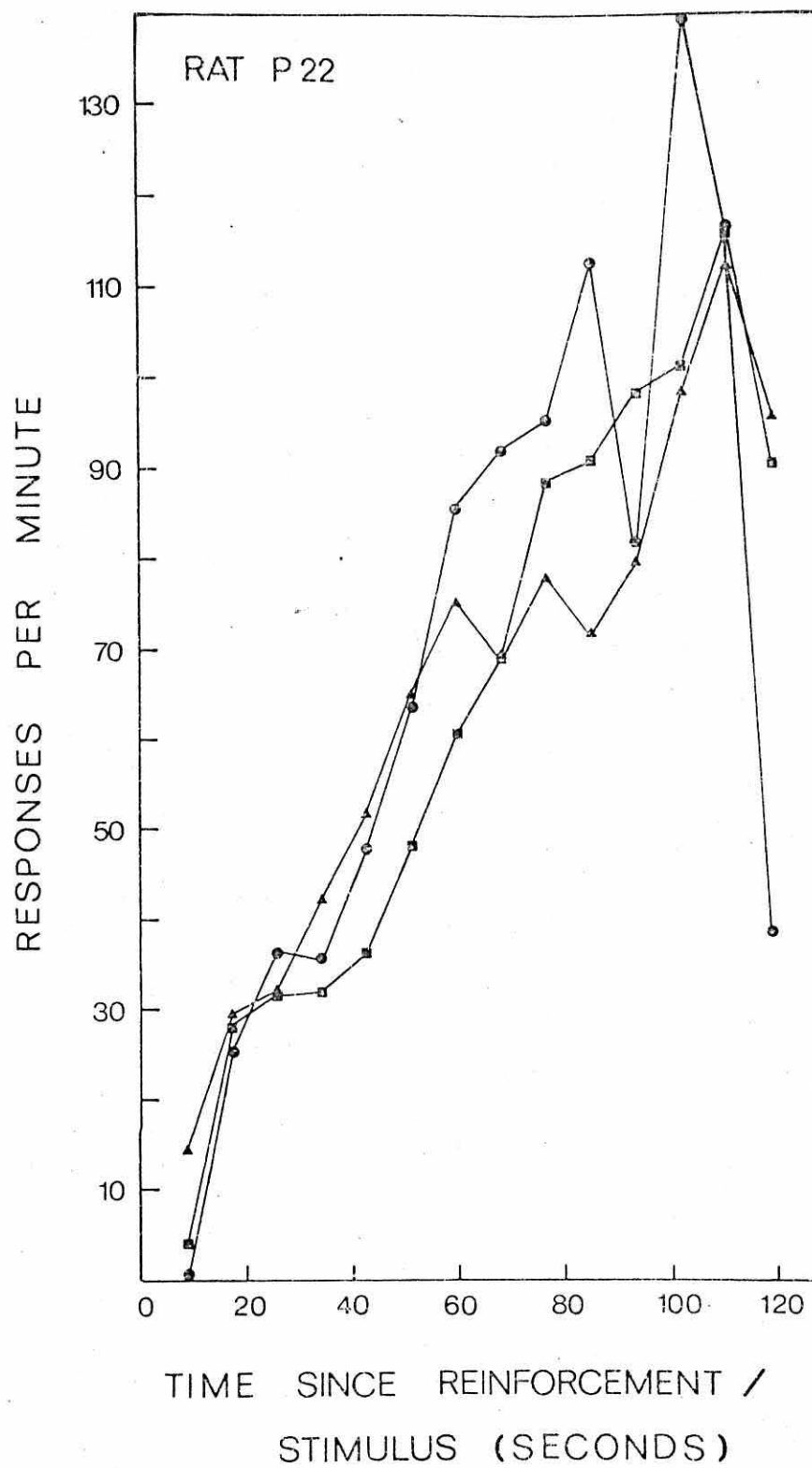
Figure 9. The rates of responding as functions of the time since reinforcement in the baseline (filled circles) and the reinforcement omission sessions (filled squares), also, the rate of responding as a function of the time since the omission stimuli (filled triangles) for Subject P13. Data are averages of the last three baseline sessions and the three reinforcement omission sessions.

RESPONSES PER MINUTE



TIME SINCE REINFORCEMENT /  
STIMULUS (SECONDS)

Figure 10. The rates of responding as functions of the time since reinforcement in the baseline (filled circles) and the reinforcement omission sessions (filled squares), also, the rate of responding as a function of the time since the omission stimuli (filled triangles) for Subject P22. Data are averages of the last three baseline sessions and the three reinforcement omission sessions.



for Subject 22, although the difference between the rates was very much smaller and disappeared relatively quickly. At longer post-reinforcement times for Subject 22 there was a higher local rate following reinforcement than following the omission stimuli. The local response rate data confirm the findings reported for running rates in Figures 5, 6 and 7, also they demonstrate that the local rate measure was more sensitive, in this case, to the effects of reinforcement omission than was the running rate measure.

#### GENERAL DISCUSSION

In Experiment 1 the duration of the post-reinforcement pause was found to be a positive function of the magnitude of reinforcement. This is in agreement with the findings of Campbell and Seiden (1974) who reported a positive relationship between volume of water, used as a reinforcer, and the duration of the post-reinforcement pause on an arithmetic VI schedule. Also, the present findings are in agreement with those from studies which have manipulated the magnitude of reinforcement on other schedules, e.g., FI (Jensen and Fallon, 1973; Lowe, et al., 1974; Staddon, 1970a) and FR (Lowe et al., 1974). The present findings do not agree, however, with those of Goodrich (1965), using

two sucrose solutions (8% and 32% concentrations) presented in a Mult. VI VI schedule. He reported a shorter pause and a higher response rate following a 32% solution of sucrose reinforcement than following an 8% solution. He attributed these results to a possible 'contrast' effect, in as much as, varying the concentration of the reinforcer on one of the VI components of the multiple schedule may have had a similar effect to varying the rate of reinforcement on a multiple schedule (e.g., Reynolds, 1961). A similar effect was reported by Griffin and Cooper (1971) using a Mult. VI VI schedule; initially the same reinforcer concentrations, i.e., 32% sucrose solution, were in effect on both VI components. The concentration of the reinforcement was subsequently reduced in one of the VI components to 8%, and this was accompanied for two of the three rats employed in the study, by a decrease in the response rate in the component with the 8% concentration, and a concomittant increase in the response rate in the unchanged component, above the previous baseline response rate. It would appear, therefore, that variations in the magnitude of reinforcement in a Mult. VI VI schedule may, as suggested by Shettleworth and Nevin (1965), have similar effects to variations in the rate of reinforcement. Also, it is possible that in the Goodrich (1965) study the shorter post-reinforcement

pause following the 32% sucrose solution, compared to the 8% solution, may have been due to an interaction between the reinforcer concentrations and the stimuli associated with each of the VI schedule components (cf. Keesey and Kling, 1961).

Guttman (1954), Jenkins and Clayton (1948), Schrier (1965), Davenport et al., (1966) and Campbell and Seiden (1974), all reported a positive relationship between overall response rate and the magnitude of reinforcement on arithmetic VI schedules. In the present experiment, however, there was considerable variation in both the overall and running rates of responding as a function of reinforcer magnitude. One consistent feature, however, was a decline in response rate at the highest magnitude; this is similar to the results reported by Conrad and Sidman (1956) who found that response rate increased as a function of sucrose concentration, but then declined at the highest concentrations. A similar effect was reported for running rate on an FR schedule by Lowe et al., (1974).

It is not clear why there was this difference between the findings of the present study and those of the other studies where the magnitude of reinforcement has been manipulated on an arithmetic VI schedule. One possibility is that the procedural differences in the manner in which the subjects were exposed to the difference reinforcer magnitudes may have contributed to the diversity in the results.

In Experiment 2 it was shown that when 50% of the scheduled reinforcements were omitted on an arithmetic VI schedule, there was a shorter pause after the stimuli presented in lieu of reinforcement than following reinforcement. This finding is in agreement with studies which have reported a similar effect, consequent to reinforcement omission, on, for example, an arithmetic VI schedule (Thomas and Blackman, 1974), an FI schedule (Kello, 1972; Staddon and Innis, 1966; 1969) and an FR schedule (McMillan, 1971). It was also found in the present experiment that although there was an elevation in the overall response rate following the omission stimuli, however, this was primarily due to a reduction in the pause following the omission stimuli, and not to any systematic increase in the running rate. This, again, is in agreement with studies that have reported that when reinforcements are randomly omitted on, for example, an FI schedule, the principal effect is a reduction in the pause following the stimulus presented in lieu of reinforcement (Kello, 1972; Staddon and Innis, 1966; 1969). However, in the present study, when responding was considered not only in terms of overall and running response rates, but also as a function of the time since either reinforcement or the omission stimuli in any one interval, there was an increase in local response rate during the early parts of the intervals initiated by the omission stimuli, (although the local rates were calculated including the pauses after reinforcement and the omission stimuli this



alone cannot account for either the magnitude of, or the persistence over time of the observed effect). On a VI schedule, running rate as a measure of responding, while excluding the post-reinforcement pause, includes responses which occur at different times after reinforcement, and is, therefore, constituted from responses which occur at short post-reinforcement times and at long post-reinforcement times. Thus, changes which, as in the present experiment, occur principally in the early periods of an inter-reinforcement interval are obscured when only the running rate is considered.

In summary, the effects of reinforcement omission on an arithmetic VI schedule are (i) a reduction in the pause following the omission stimuli, and (ii) an elevation in the local response rate at early times in the intervals initiated by the omission stimuli.

These findings are consistent with Staddon's (1970b) theoretical interpretation of the reinforcement omission effect, i.e., in terms of the generalization of the inhibitory after-effects of reinforcement (outlined in Chapter 2). However, the present data are also consistent with a 'frustration' explanation of the omission effect. Amsel (1958) defined frustration as, "...an increase in

the vigour of responding which immediately follows frustrating events' (p.103), a 'frustrating' event being 'the absence of or delay of, a reward event in a situation where it has been present previously (p.102)'. The data from the present study does not provide a basis for any decision as to the validity of either explanation.

One feature of the data from both the present experiments is that, despite inter-subject variability, for all subjects, the local response rate was a negatively accelerated function of the time since reinforcement. Similar functions have been reported by Catania and Reynolds (1968) for pigeons responding on various values of an arithmetic VI schedule, and it suggests that the local response rate on such a VI schedule tends to match the changes in the probability of reinforcement over time.

In summary, the findings reported in the present Chapter are consistent with the notion, outlined in the introduction, that the reinforcing stimuli on an arithmetic VI schedule may acquire inhibitory after-effects, and that these after-effects are enhanced when the magnitude of the reinforcement is increased and are reduced when the reinforcement is omitted.

## CHAPTER 5

### CONSTANT PROBABILITY VI SCHEDULES OF REINFORCEMENT

In Chapter 4 it was suggested that on an arithmetic VI schedule the reinforcing stimulus has inhibitory after-effects. Also, it was suggested that this was because the occurrence of a reinforcer on an arithmetic VI schedule is followed by a period of time during which there is a low probability of the next reinforcement occurring (this probability gradually increases as does the time since the last reinforcement). In other words, the reinforcer becomes a signal for a period of low

reinforcement probability. In the present Chapter the after-effects of the reinforcement were investigated on a VI schedule where, rather than the reinforcer signalling a period of low reinforcement probability, the probability of reinforcement remains constant irrespective of the time that has elapsed since the preceeding reinforcement. A VI schedule which generates such a sequence of reinforcement probabilities is a constant probability VI (Cantania and Reynolds, 1968; Fleshler and Hoffman, 1962).

On a constant probability VI schedule there is approximately a constant probability of reinforcement occurring at almost all possible post-reinforcement times (although there must be, in the ex post facto sense, a longest inter-reinforcement interval where the probability of reinforcement occurring must reach a value of  $p=1.0$ ). A constant probability VI schedule, therefore, is one where there is a minimal correlation between probability of reinforcement and the time since the last reinforcement, thus ensuring that time since reinforcement cannot acquire discriminative control over responding through its relationships to the availability of subsequent reinforcement. It is possible that such a condition may be a prerequisite for a local rate of responding that is constant in relation to increasing post-reinforcement time.

There are two methods of designing constant probability VI schedules. In one method the separation in time of successive opportunities for reinforcement is held constant while the relative frequencies of different intervals are varied; such schedules are usually termed random-interval (RI) schedules, e.g., Farmer (1968), Millenson (1963). In the other method the relative frequencies of different intervals are held constant while the separation in time of successive opportunities for reinforcement is varied; such a method is exemplified in the formulae of Fleshler and Hoffman (1962) and Catania and Reynolds (1968). In the present experiment the latter method was adopted.

Catania and Reynolds (1968) exposed pigeons to various values of a constant probability VI schedule; they found that after reinforcement there was a low response rate, initially, followed by an approximately constant response rate (local response rate) for the remainder of the inter-reinforcement interval (cf. an arithmetic VI where response rate is a negatively accelerating function of time since reinforcement). Similar effects have been reported by Farmer (1963) and Millenson (1963) using pigeons exposed to various values of an RI schedule.

There is also evidence to suggest that on an RI schedule the duration of the post-reinforcement pause is related to the mean inter-reinforcement interval (cf. FI schedules). Lachter (1970) using an RI schedule in which  $p$  (probability of reinforcement) was held constant and  $T$  (time between opportunities for reinforcement) varied from 0 to 24-sec found that the duration of the post-reinforcement pause was a monotonically increasing function of the mean inter-reinforcement interval ( $\frac{T}{p}$ ). A similar effect has been reported when the  $T$  value was held constant at 30-sec and the  $p$  value varied (Martin, 1971). This relationship between post-reinforcement pause durations and mean inter-reinforcement interval has also been reported by Farmer (1963) using a range of different  $T$  and  $p$  values.

It thus appears that on RI schedules, to the extent that the reinforcing stimulus initiates a certain period of non-reinforcement, a pause occurs after reinforcement. For example, on an RI schedule, when  $T = 10$ -sec the occurrence of reinforcement 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 experiments reported in the present Chapter investigated the after-effects of the reinforcing stimulus on a constant probability VI schedule. The sequence of inter-reinforcement intervals used was generated from the formula given by Catania and Reynolds (1968), this being a modification of Fleshler and Hoffman's (1962) formula. In the present study the schedule had a mean inter-reinforcement time of 60-sec.

In Experiment 3 the magnitude of reinforcement was manipulated, and in Experiment 4 50% of the scheduled reinforcements were omitted. The effects of these manipulations were considered in relation to the pauses, overall rates, running rates, and local response rates generated by this schedule.

### EXPERIMENT 3

#### MANIPULATION OF THE MAGNITUDE OF REINFORCEMENT

##### METHOD

##### Subjects

Three male hooded rats (14, 15 and 16) served as subjects. They were housed individually and had ad lib. access to water in the home cages. They were maintained at approximately 80% of their free-feeding weights throughout the experiment.

##### Apparatus

The basic apparatus was described in Chapter 3. In addition to this, in the present experiment the constant probability VI was scheduled using a continuously driven loop of punched tape. The punched holes in the tape provided a series of intervals, derived from the formula given by Catania and Reynolds (1968), which occurred in the sequence: 36.0, 52.1, 17.9, 139.1, 12.9, 109.1, 43.0, 23.4, 4.0, 62.1, 199.1, 74.1, 29.4, 89.1, 8.3 (seconds) with a mean of 60.0-sec.



## Procedure

### Training

The subjects were first lever trained, after which they were immediately placed on the constant probability VI 60-sec schedule. Throughout the training phase the reinforcer was a 40% solution of Nestlé's condensed milk in water. The subjects were run daily until the mean daily response rate over 5 successive sessions did not differ by more than  $\pm 10\%$  of the mean of the 5 sessions. For Subject 14 this was 66 sessions; for Subject 15 it was after 68 sessions, and for Subject 16 after 65 sessions. The first response in each session was reinforced and the VI schedule then operated, beginning at a different place in the series of intervals in successive sessions. Sessions ended after each interval in the series had occurred four times (61 reinforcements). The duration of each session was, therefore, approximately one hour.

### Testing

The same schedule was in effect as during the training phase. Four different reinforcer concentrations 0% (water), 20%, 40% and 60% were presented in blocks of 5 reinforcements. The order of the blocks was random, with the constraint that, in each session, each block occurred three times. Three test sessions were conducted each consisting of 60 reinforcements. After this the subjects were returned to the baseline conditions.

## RESULTS

Figure 11 (left hand panel) shows the median duration of the post-reinforcement pause as a function of the preceding reinforcer concentration (see Table 4 for the interquartile ranges). In all instances the duration of the post-reinforcement pause was positively related to the reinforcer magnitude, however, this effect was relatively small. The range of the difference between the pause following the 0% concentration and that following the 60% concentration was 2.5-sec for Subject 14; for Subject 15 this difference was 2.0-sec; and Subject 16 it was 2.0-sec. Table 5 shows the mean duration of the post-reinforcement pause as a function of position in a test block, for the different concentrations. Immediately subsequent to the presentation of a new reinforcer concentration the duration of the post-reinforcement pause changed appropriately, however, at the final presentation within a block of any one reinforcer concentrations the differences between the post-reinforcement pauses following the 20%, 40% and 60% concentrations had decreased.

The centre panel of Figure 11 shows the mean running rates for all the subjects as a function of reinforcer concentration. For Subject 14 running rate was an increasing function of reinforcer concentration; for Subject 15 rate increased at all concentrations reaching a

Figure 11. The median post-reinforcement pause (left panel), the mean running rate (centre panel), and the mean overall rate (right panel) as functions of the preceding reinforcer magnitude. The unconnected points represent the baseline data. For each subject data were taken from the last three baseline sessions and the three test sessions.

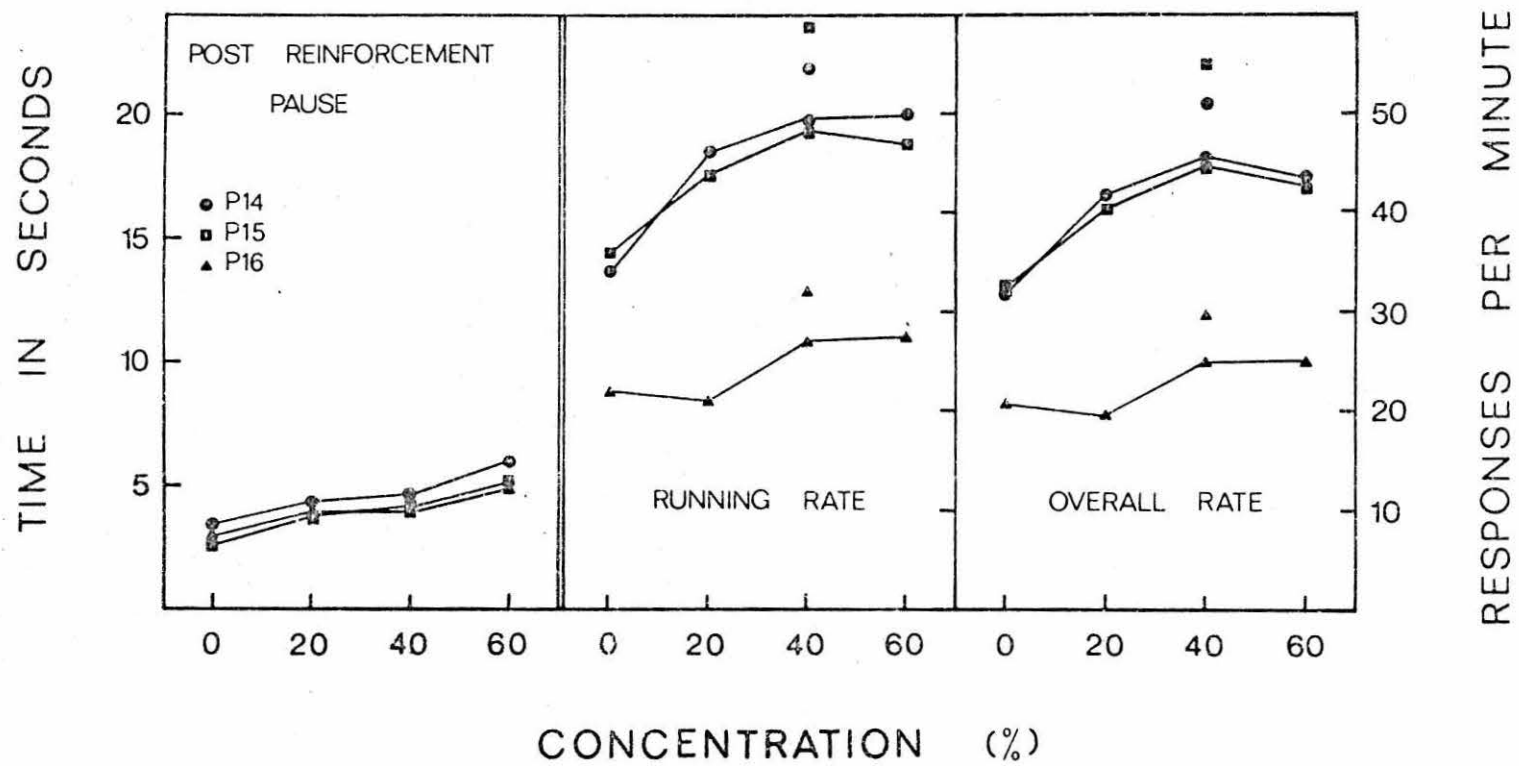


TABLE 4

The interquartile ranges of the post-reinforcement pause durations as a function of the preceeding reinforcer concentration. Data are from the last three baseline sessions and the three test sessions.

ANIMAL	CONCENTRATION	POST-REINFORCEMENT PAUSE IN SECONDS	
		BASELINE	TEST
14	0%		2.5 - 4.4
	20%		3.7 - 4.9
	40%	3.5 - 4.8	4.0 - 5.2
	60%		5.2 - 7.3
15	0%		0.9 - 3.9
	20%		3.3 - 4.5
	40%	4.0 - 4.8	3.5 - 4.7
	60%		4.3 - 5.9
16	0%		2.3 - 4.2
	20%		3.4 - 4.7
	40%	3.5 - 4.7	3.4 - 4.8
	60%		4.2 - 5.8

TABLE 5

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

CONCENTRATION	ANIMAL	ORDINAL POSITION				
		1	2	3	4	5
0%	14	4.4	3.7	3.1	3.9	3.4
	15	3.5	3.8	3.1	2.3	2.4
	16	4.4	3.5	3.4	3.1	2.7
	MEAN	4.1	3.7	3.2	3.1	2.8
20%	14	4.7	4.7	4.2	4.3	4.0
	15	4.9	3.8	3.9	3.5	3.9
	16	4.6	4.3	3.8	3.8	4.4
	MEAN	4.7	4.3	4.0	3.9	4.1
40%	14	5.2	4.6	4.9	4.5	4.2
	15	4.7	4.7	4.1	4.0	4.1
	16	4.8	4.4	4.0	4.7	3.8
	MEAN	4.9	4.6	4.3	4.4	4.0
60%	14	7.9	7.2	6.6	7.1	6.1
	15	7.0	6.1	5.1	5.0	4.1
	16	6.8	5.3	5.2	5.2	4.5
	MEAN	7.2	6.2	5.6	5.8	4.9

maximum at the 40% concentration and then declined slightly at the highest magnitude; for Subject 16 rate decreased from the 0% to the 20% concentrations and then increased at both the 40% and 60% concentrations. The functions relating overall response rate (right hand panel, figure 11) to reinforcer concentration were similar in every respect to those observed for running rate, with the exception of Subject 14. In the case of Subject 14 there was a decline in the overall rate from the 40% to 60% concentrations, whereas running rate increased at this point.

Figures 12, 13 and 14 show the mean local response rates following the different reinforcement concentrations for the last three baseline sessions and the three test sessions. Generally, local response rate did not change systematically as a function of time since reinforcement (cf. Experiment 1, where response rate was a negatively accelerated function of time since reinforcement). For Subject 14, although there was considerable variation in the local rate over time since reinforcement, there was little systematic difference between the local rates following the different concentrations, however, in all instances, response rate declined at the longer post-reinforcement times. Similar effects were observed for

Figure 12. The rates of responding following the different reinforcer magnitudes as functions of the time since reinforcement on a constant probability VI 60-sec schedule for Subject P14. Data are averages of the last three baseline sessions (B) and the three test sessions.



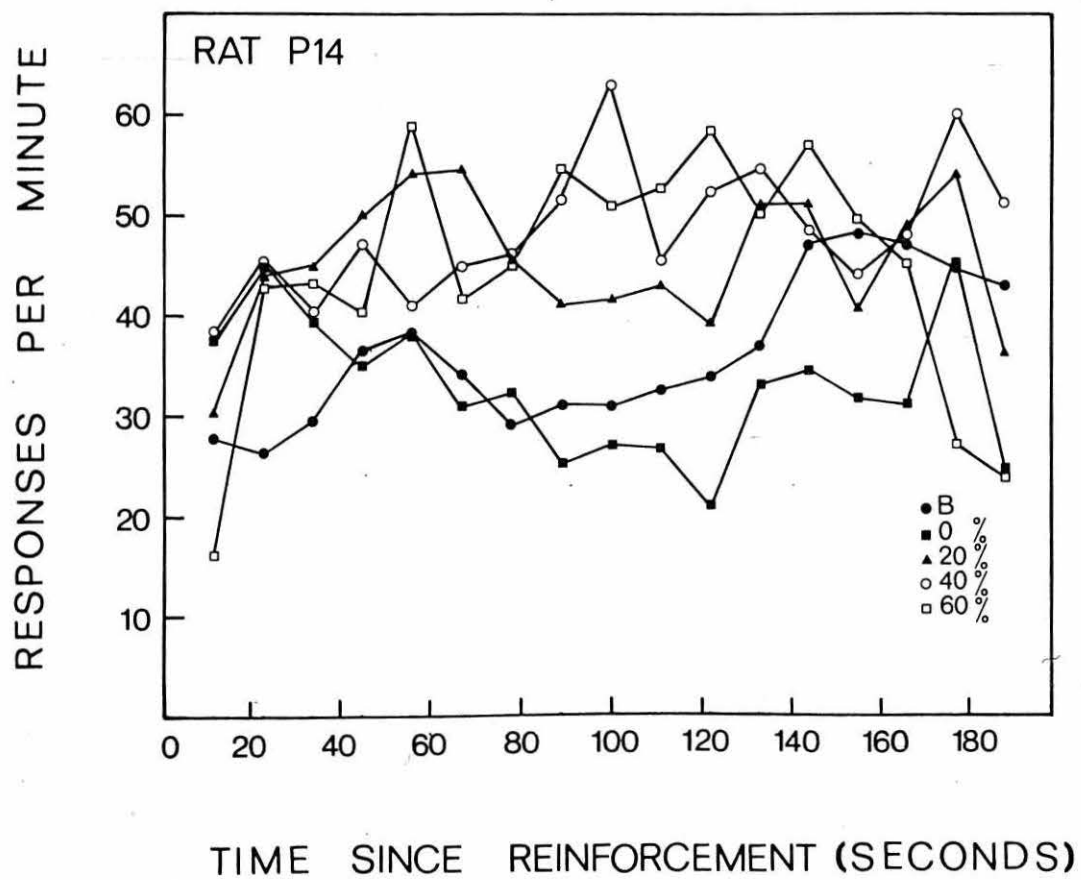


Figure 13. The rates of responding following the different reinforcer magnitudes as functions of the time since reinforcement on a constant probability VI 60-sec schedule for Subject P15. Data are averages of the last three baseline sessions (B) and the three test sessions.

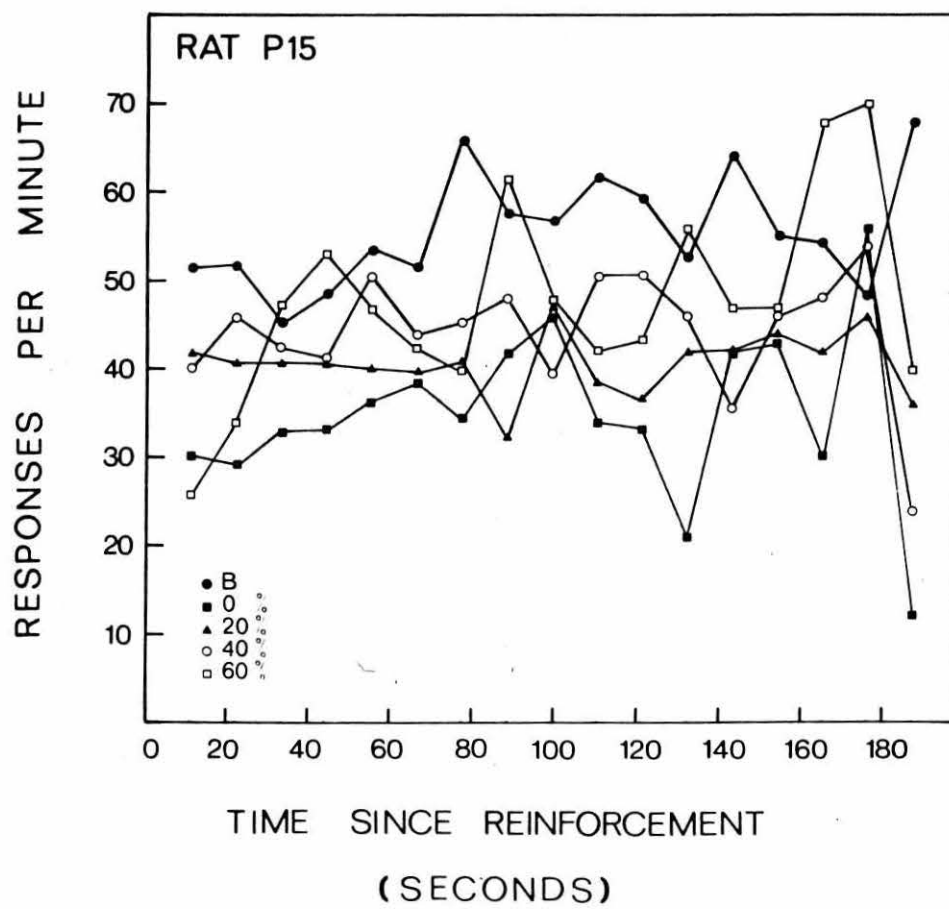
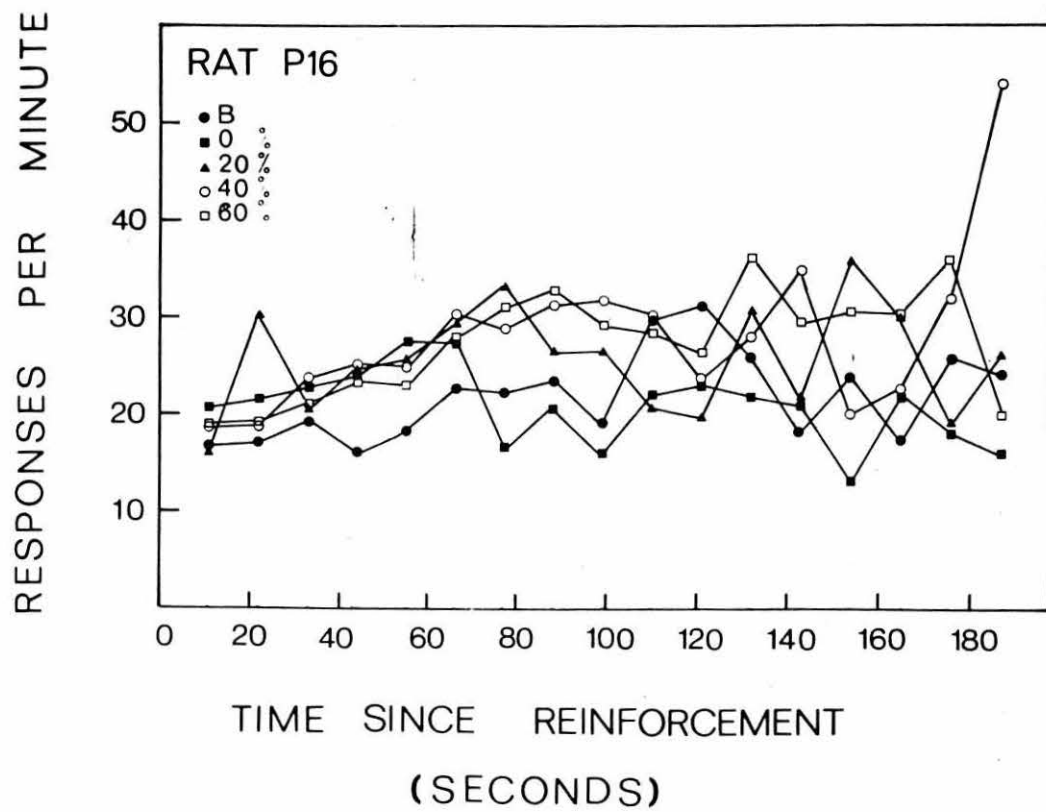


Figure 14. The rates of responding following the different reinforcer magnitudes as functions of the time since reinforcement on a constant probability VI 60-sec schedule for Subject P16. Data are averages of the last three baseline sessions (B) and the three test sessions.



Subjects 15 and 16 with the exception that, for Subject 16 there was a very marked increase in the response rate following the 40% concentration at the longer post-reinforcement times. For all the subjects there was a lower rate of responding in the early periods after the 60% concentration reinforcers, followed by a steep increase in rate.

#### EXPERIMENT 4

##### THE OMISSION OF REINFORCEMENT

In this experiment the effects of omitting 50% of the scheduled reinforcements on a constant probability VI 60-sec schedule were investigated.

McMillan (1971) exposed pigeons to a constant probability VI 60-sec schedule (derived from the formula given by Catania and Reynolds, 1968). When 50% of the scheduled reinforcements were randomly omitted and replaced by a 4-sec T0 - of the same duration as reinforcement - the duration of the pause following the omission stimulus was greater than the duration of the

post-reinforcement pause. For one of the pigeons the pause following the omission stimulus was approximately 3-sec compared to a post-reinforcement pause of less than 1-sec, and for the other pigeon the post omission pause was approximately 2-sec and the post-reinforcement pause again was less than 1-sec.

These results are contradictory to the effects of reinforcement omission observed on other schedules. Generally, on other schedules, the duration of the pause following the omission stimulus is less than the duration of the post-reinforcement pause, i.e., the converse of McMillan's findings. This has been reliably reported on, for example, FI schedules (Kello, 1972; Staddon and Innis, 1966; 1969), FR schedules (McMillan, 1971), VR schedules (Chapter 7), and arithmetic VI schedules (Thomas and Blackman, 1974; Chapter 4).

Revusky (cited in Staddon, 1970b) and also Staddon (1970b) have found that on a VI schedule which generated a constant response rate over time reinforcement omission had virtually no effect upon responding.

Staddon (1974) has argued that the results of McMillan's (1971) experiment, i.e., a longer pause after the omission stimulus than following reinforcement,

provides strong evidence against any account of the reinforcement omission effect in terms of the frustrative effects of non-reward. However, it is not clear from the studies of McMillan (1971), and of Staddon (1970b) what effect the omission of reinforcement had on the response rates following reinforcement and following the omission stimuli. Also in McMillan's (1971) experiment the reinforcement cycle consisted of a 3.5-sec hopper presentation followed by a 0.5-sec T0, and it is possible that this may have contributed to the very short post-reinforcement pause durations (less than 1-sec) that were observed. In comparison, Martin (1971) reported post-reinforcement pause durations of approximately 9-sec with pigeons exposed to a random interval schedule with a similar mean inter-reinforcement interval, i.e., 60-sec. The present experiment was designed to overcome such procedural difficulties and also to provide a fuller analysis of the effects of reinforcement omission on the behaviour produced by a constant probability VI schedule.



## METHOD

### Subjects

Rats 14, 15 and 16 served as subjects. They had previous experience on a constant probability VI 60-sec schedule. They were housed and maintained as before.

### Apparatus

The experimental box, scheduling and recording equipment was the same as used in Experiment 3. The tone stimulus (with a frequency of 1000 Hz) was produced by directing the output of a frequency generator through an amplifier, to a 6-inch 15 ohm speaker located on the lid of the experimental box. The intensity of this tone was 85 db. The light stimulus was produced by 2 x 12 Watt 24V DC bulbs located on the front panel of the experimental box.

### Procedure

The subjects were exposed to the same constant probability VI schedule as in Experiment 3, with the addition that each reinforcement was accompanied by a 0.5 sec tone + light stimulus. Sessions were conducted

as in Experiment 3, with the concentration of the reinforcer kept at 40% throughout the experiment. A minimum of 25 daily sessions were conducted, and the subjects were judged to be stable when, after the 25th session, the mean response rate for any one of 5 consecutive sessions did not differ by more than  $\pm 10\%$  of the mean response rate of the 5 sessions. Once the behaviour was stable (for Subjects 14, 15 and 16 the number of sessions were 34, 42, and 37 respectively), the subjects were exposed to a procedure where 50% of the scheduled reinforcements were omitted in a random manner; each interval therefore, ended in either reinforcement + stimuli or stimuli alone. This procedure was in effect for three sessions after which the subjects were returned to a condition with a 100% reinforcement on the VI schedule.

## RESULTS

Figures 15, 16 and 17 (upper panels) show for Subjects 14, 15 and 16 respectively, the mean duration of the post-reinforcement pause and of the post-omission stimuli pause for the last five baseline sessions, the three reinforcement omission sessions, and the first five return-to-baseline sessions. In all instances there was a small

Figure 15 The upper panel shows the mean durations of the post-reinforcement pause (filled circles) and the post omission stimuli pause (filled squares). The lower panel shows the running rates following reinforcement (filled circles) and following the omission stimuli (filled squares). The unconnected points represent the means of the baseline and return-to-baseline sessions. Data are from the last five baseline sessions (31-35), the three reinforcement omission sessions (36-38) and the first five return-to-baseline sessions (39-43) for Subject P14.

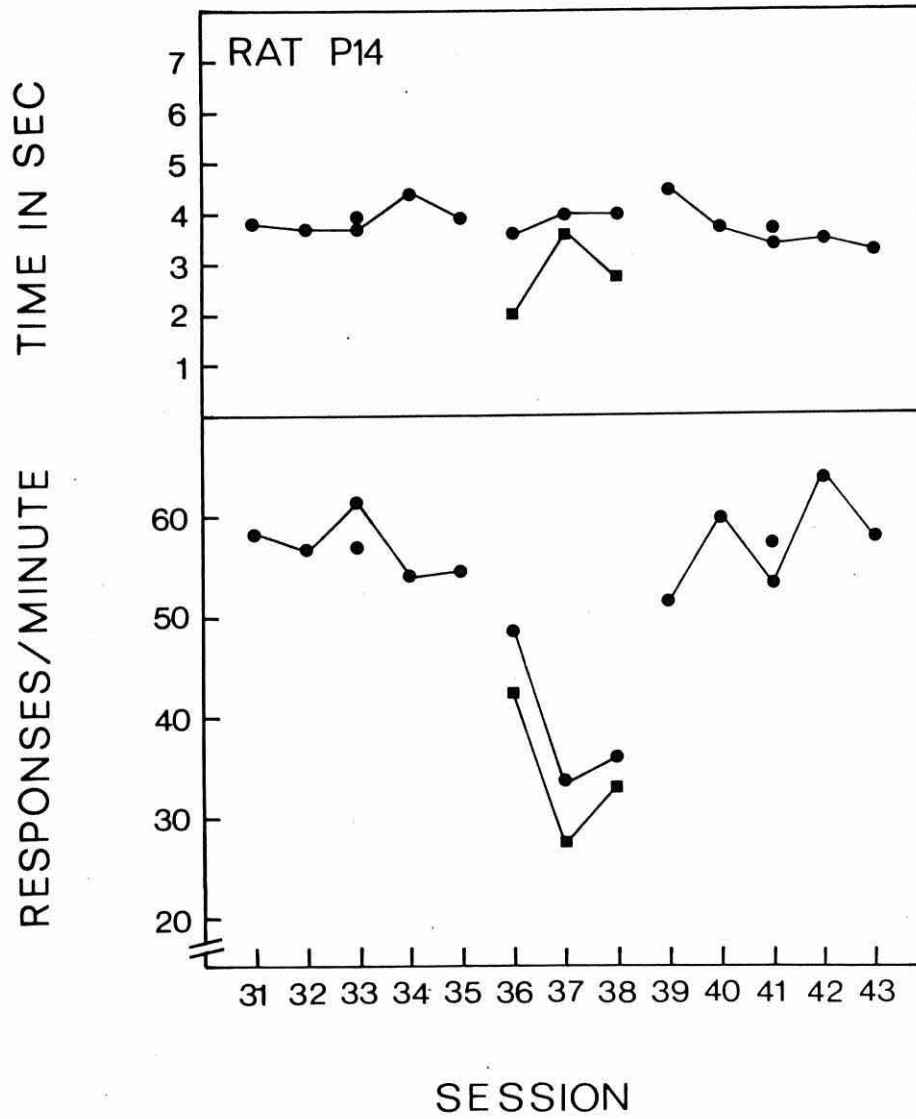


Figure 16. The upper panel shows the mean durations of the post-reinforcement pause (filled circles) and the post omission stimuli pause (filled squares). The lower panel shows the running rates following reinforcement (filled circles) and following the omission stimuli (filled squares). The unconnected points represent the means of the baseline and return-to-baseline sessions. Data are from the last five baseline sessions (38-42), the three reinforcement omission sessions (43-45) and the first five return-to-baseline sessions (46-50) for Subject P15.

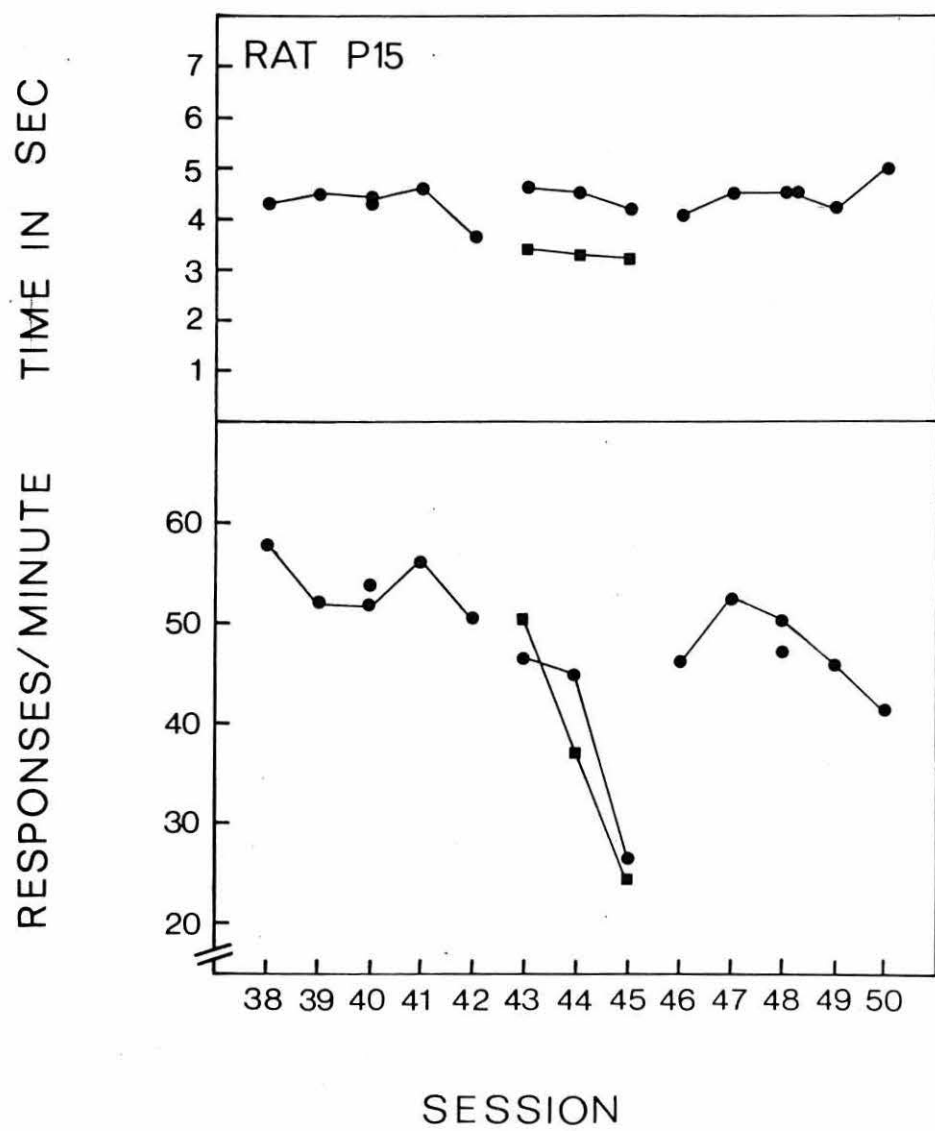
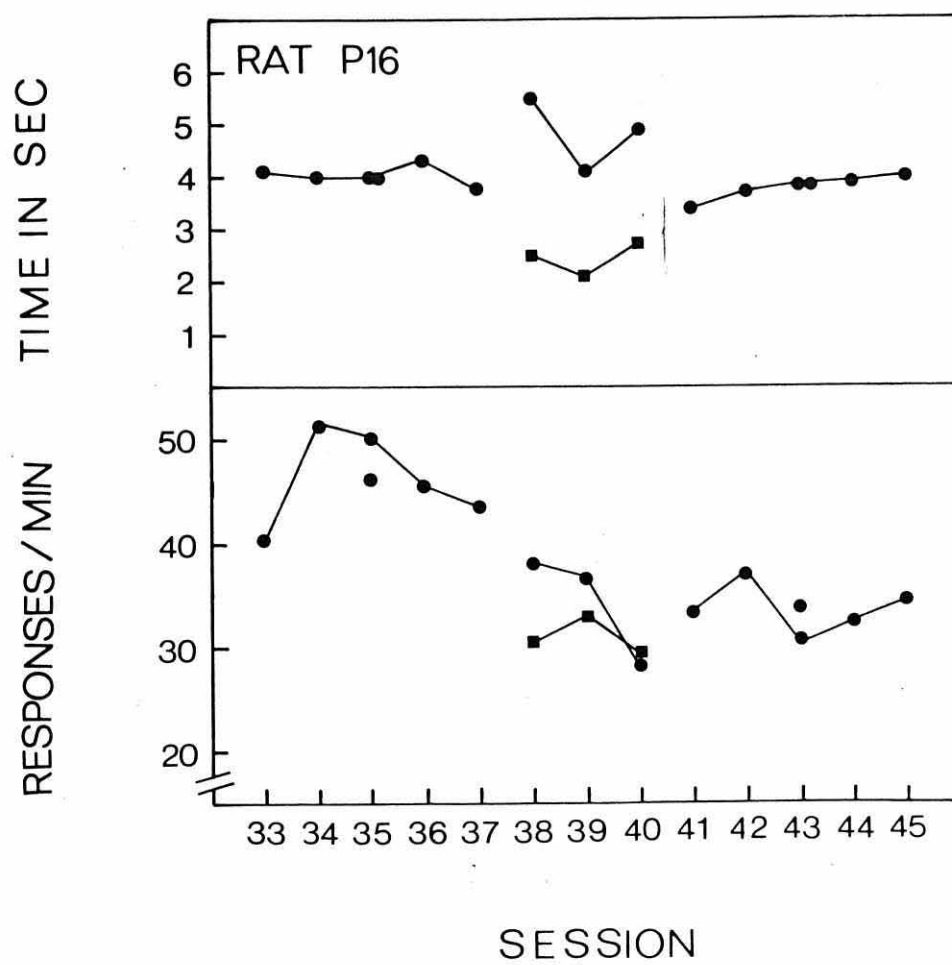


Figure 17. The upper panel shows the mean durations of the post-reinforcement pause (filled circles) and the post omission stimuli pause (filled squares). The lower panel shows the running rates following reinforcement (filled circles) and following the omission stimuli (filled squares). The unconnected points represent the means of the baseline and return-to-baseline sessions. Data are from the last five baseline sessions (33-37), the three reinforcement omission sessions (38-40), and the first five return-to-baseline sessions (41-45) for Subject P16..





but systematic reduction in the pause following the omission stimuli compared to the duration of the post-reinforcement pause. The duration of the post-reinforcement pause in the baseline, omission and return-to-baseline sessions for Subjects 14 and 15 did not show any systematic variation; for Subject 16 there was a slight increase in post-reinforcement pause duration in the omission sessions relative to the baseline sessions. However, this was not sustained in the return-to-baseline sessions.

Running rate (lower panels of Figures 15, 16 and 17) was, generally, lower following the omission stimuli than following reinforcement; for Subject 15 rate following the omission stimuli was lower than rate following reinforcement, with the exception of the first omission session; and for Subject 16 rate was lower following the omission stimuli in the first two omission sessions. In all instances the running rates following the omission stimuli and following reinforcement were both lower compared to the running rate in the baseline sessions and, with the exception of Subject 14, decreased further in the return-to-baseline sessions. In the case of Subject 14 there was little difference between the running rate in the baseline and return-to-baseline sessions. Similar effects were observed for the overall response rates in the baseline, omission, and return-to-baseline sessions (Table 6).

TABLE 6

Mean overall rates of responding. Data are from the last five baseline sessions, the three reinforcement omission sessions and the first five return-to-baseline sessions.

ANIMAL	BASELINE	OMISSION FOLLOWING:			RETURN-TO- BASELINE
		REINFORCEMENT STIMULI			
14	53.9	36.7	32.7	54.0	
15	49.6	35.9	35.0	43.6	
16	43.9	31.2	29.8	31.6	

Figures 18, 19 and 20 show the mean local response rates for the last three baseline sessions and the three reinforcement omission sessions for Subjects 14, 15 and 16 respectively. In the baseline sessions response rate was not systematically related to the time elapsed since reinforcement, i.e., response rate was more or less constant at varying times since reinforcement. The post-reinforcement pauses, although included in the calculation of the local rates, were of very short duration and, consequently, made little contribution to the local rate functions described.

In the omission sessions the local response rates following the omission stimuli and following reinforcement were both lower than the response rates in the baseline sessions, (cf. the running rate data shown in Figures 15, 16 and 17). There was considerable variation in the local response rates both following reinforcement and following the omission stimuli during the latter periods of the longer inter-reinforcement intervals. However, one consistent feature was that, in all instances, there were lower local rates of responding during the early periods of those intervals initiated by the omission stimuli, than during the comparable periods of those intervals following reinforcement. The local rate functions

Figure 18. The rates of responding as functions of the time since reinforcement in the baseline (filled circles) and the reinforcement omission sessions (filled squares), also, the rate of responding as a function of the time since the omission stimuli (filled triangles) for Subject P14. Data are averages of the last three baseline sessions and the three reinforcement omission sessions.

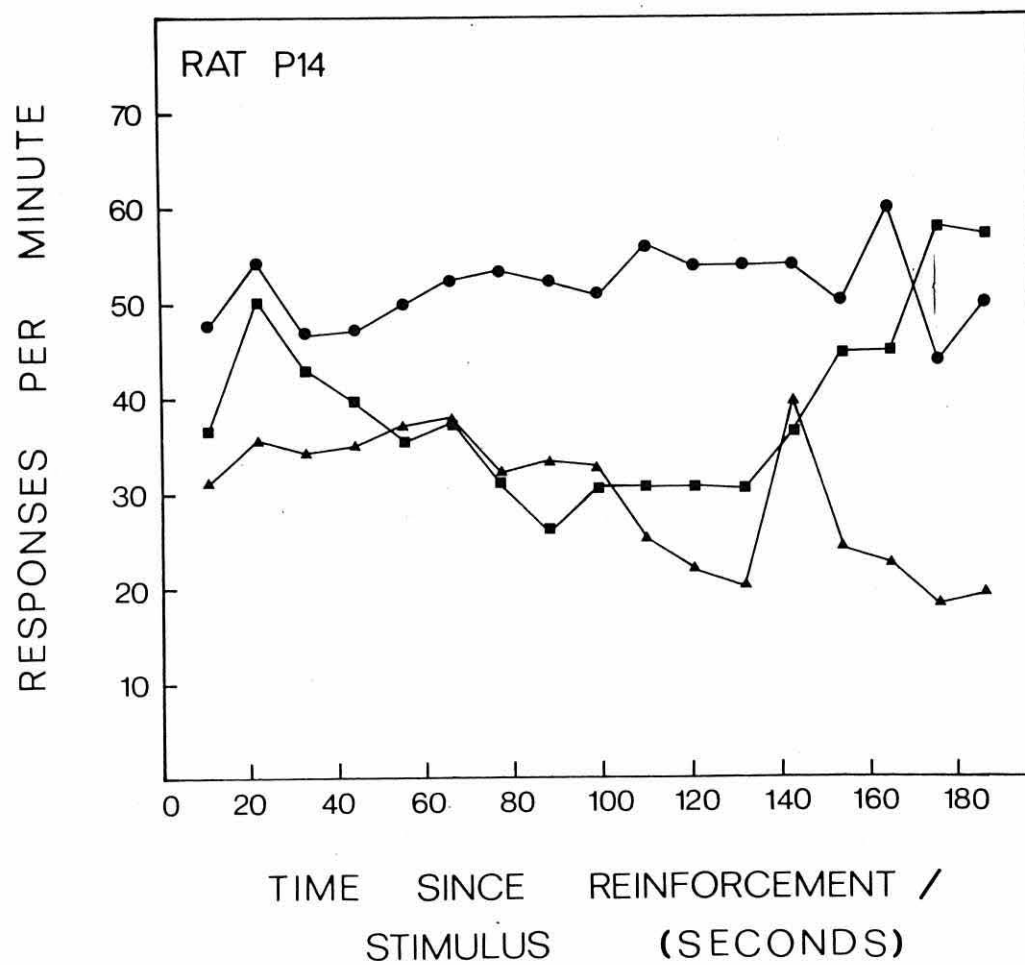


Figure 19. The rates of responding as functions of the time since reinforcement in the baseline (filled circles) and the reinforcement omission sessions (filled squares), also, the rate of responding as a function of the time since the omission stimuli (filled triangles) for Subject P15. Data are averages of the last three baseline sessions and the three reinforcement omission sessions.

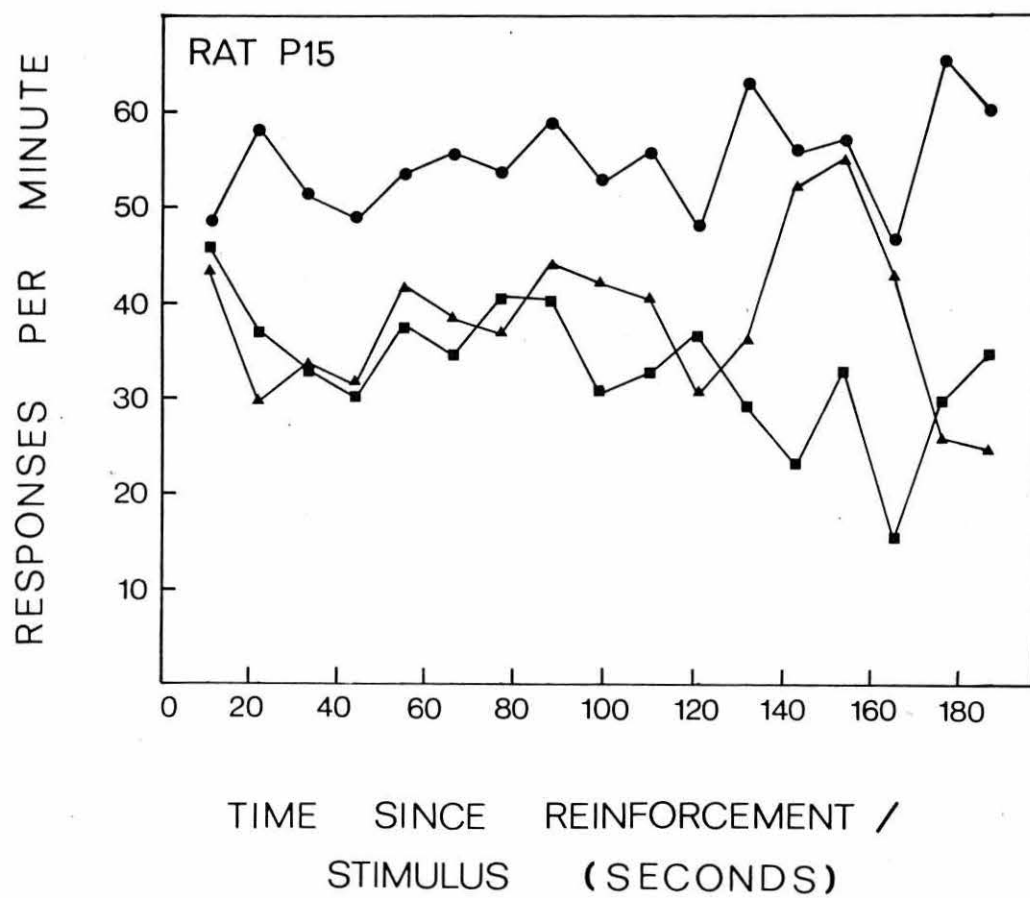
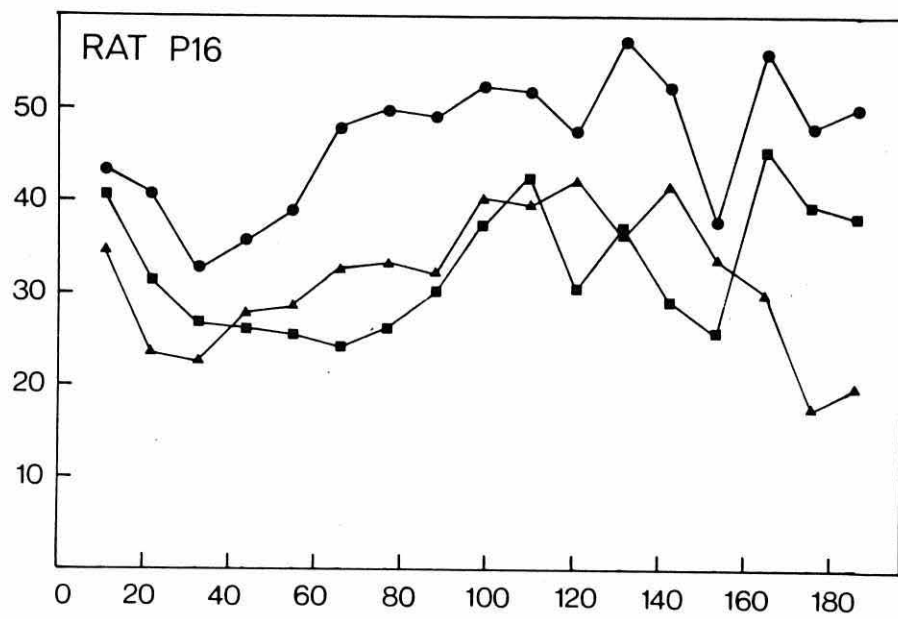


Figure 20. The rates of responding as functions of the time since reinforcement in the baseline (filled circles) and the reinforcement omissions sessions (filled squares), also, the rate of responding as a function of the time since the omission stimuli (filled triangles) for Subject P16. Data are averages of the last three baseline sessions and the three reinforcement omission sessions.



RESPONSES PER MINUTE



TIME SINCE REINFORCEMENT /  
STIMULUS (SECONDS)

describe more precisely the running data shown in Figures 15, 16 and 17.

#### GENERAL DISCUSSION

On a constant probability VI schedule the distribution of inter-reinforcement intervals arranges so that there is a minimal correlation between time since reinforcement and the availability of subsequent reinforcement, i.e., probability of reinforcement is an approximately constant function of the time elapsed since reinforcement. Catania and Reynolds (1968) found that response rate, as a function of time elapses since reinforcement, tended to match the variations in the probability of reinforcement at different post-reinforcement times on a number of different VI schedules, for example, arithmetic, geometric, and linear VI schedules. On a constant probability VI they found that response rate was approximately constant in relation to time since reinforcement, with little systematic deviation from this function. Similar effects were found in the present experiments with rats exposed to a constant probability VI schedule, also, it was found that the duration of the post-reinforcement pause produced by the schedule was relatively short, i.e., approximately 4-sec; considerably less than the pause produced by an arithmetic VI schedule

with a comparable mean inter-reinforcement interval (cf. Experiments 1 and 2). This difference observed in the duration of the post-reinforcement pauses raises the question as to what are the determinants of pause duration on VI schedules.

In the present instance, both the arithmetic and the constant probability VI schedules had the same mean inter-reinforcement interval, i.e., 60-sec; yet the duration of the post-reinforcement pause produced by the former schedule, i.e., approximately 10-15 sec, was longer than the pause produced by the latter, i.e., approximately 4-sec. The schedules did differ, however, in terms of the values of the various inter-reinforcement intervals around the mean value. For example, on the arithmetic VI schedules the maximum interval value was 120-sec while on the constant probability VI schedule it was 190-sec. Nonetheless, the pause was shorter on the latter schedule than on the arithmetic VI schedule. Another difference between the two VI schedules was in terms of the relative probabilities of reinforcement at different times following a reinforcement. That is, the probability at any one post-reinforcement time relative to the probability at any other time. On the arithmetic VI schedule there was a low probability at short post-reinforcement times compared to the longer post-reinforcement times. On the other hand, on the constant probability VI schedule the probability of reinforcement remained constant

at almost all post-reinforcement times. It is possible, therefore, that the longer pause observed on the arithmetic VI schedule resulted from the fact that the occurrence of a reinforcer predicted a period of relatively low reinforcement probability (cf. FI schedules). On the constant probability VI schedule, however, this was not the case.

In any attempt to account for the observed duration of the post-reinforcement pause on VI schedules another factor must also be taken into account, that is, the absolute probability of reinforcement. This is determined by the mean value of the interval, for example, at any particular post-reinforcement time on a specified VI schedule, the probability of reinforcement occurring at that time will vary according to the value of the mean inter-reinforcement interval. However, as any variation in the mean interval value will also affect the probability of reinforcement at all other post-reinforcement times, to the same degree, the relative probabilities of reinforcement at the different times will remain the same.

Staddon (1972a) has argued that on most schedules of reinforcement the reinforcing stimulus is a temporal predictor of a period of non-reinforcement and, consequently, it acquires conditioned inhibitory after-effects. In Chapter

2 it was argued that such an analysis could be applied to FI and FR schedule behaviour. Similarly, it was suggested that if the reinforcer acquires conditioned inhibitory after-effects on a schedule of reinforcement, these are enhanced when the magnitude of the reinforcement is increased. This has been demonstrated on, for example, FI schedules (Jensen and Fallon, 1973; Lowe et al., 1974; Staddon, 1970a), and FR schedules (Lowe et al., 1974). Also the experiments reported in Chapter 4 show that this is also the case on an arithmetic VI schedule.

The reinforcing stimulus ought not to acquire inhibitory after-effects according to Staddon's hypothesis, when, on a schedule of reinforcement, the occurrence of a reinforcer does not signal any change in the probability of the next reinforcement occurring. The constant probability VI schedule used in the present experiments meets these requirements. However, in Experiment 3 it was found, contrary to the prediction of Staddon's hypothesis, that the duration of the post-reinforcement pause was a positive function of the magnitude of the reinforcement. It is worth noting, however, that the differences observed in the duration of the post-reinforcement pauses following the different reinforcer magnitudes were relatively small, and may have been due to differences in eating time owing to the changes in the consistency of the milk solution

used as the reinforcer. Nonetheless, the function relating post-reinforcement pause duration to reinforcer magnitude was consistent, both within and between subjects.

The overall response rates and the running rates in the present experiment tended to increase with increases in the magnitude of reinforcement, although this effect was not consistently observed for all of the subjects. Similar effects were reported by Lowe et al., (1974), when the magnitude of reinforcement was manipulated on an FR schedule and a Tand. FR1 FI schedule.

In Experiment 4 it was found that when 50% of the scheduled reinforcements were omitted on a constant probability VI schedule, and 'neutral' stimuli presented in lieu of reinforcement, the duration of the pause following the omission stimuli was shorter than the duration of the post-reinforcement pause. Similar effects have been reported using this procedure, on, for example, FI schedules (Kello, 1972; Staddon and Innis, 1966; 1969), FR schedules (McMillan, 1971), arithmetic VI schedules (Thomas and Blackman, 1974; Chapter 4), and VR schedules (Chapter 7). The present findings, however, are contrary to those of McMillan (1971). He found that when 50% of the scheduled reinforcements were omitted on a constant

probability VI schedule, the duration of the post omission stimulus pause was greater than the duration of the post-reinforcement pause, i.e., the opposite of the present findings. It is not clear why these differences exist between McMillan's results and those of the present experiment. In both instances, the sequence of inter-reinforcement intervals was derived from the same formula, (Catania and Reynolds, 1968) and had the same mean inter-reinforcement interval. The studies do differ, however, on a number of procedural details, and these may account, at least in part, for the conflicting findings. For example, in McMillan's (1971) experiment pigeons were used as subjects and the reinforcement consisted of 3.5-sec access to grain followed by a 0.5-sec T0. The stimulus presented in lieu of reinforcement was a 4.0-sec T0. In the present study on the other hand, rats served as subjects and the reinforcement was a measured quantity of a milk solution. A 0.5 sec tone + light stimulus accompanied each reinforcement and was also the stimulus presented in lieu of reinforcement.

Explanations of the reinforcement omission effect have resolved around two theoretical approaches; firstly, that the enhancement of responding following the omission of an expected reward is attributable to increased response vigour elicited by non-reward, e.g., frustration

theory (Amsel, 1938; 1962; Amsel and Roussel, 1952). Secondly, it has been suggested that this response enhancement is due to the absence of the inhibiting effects which accompany reinforcement (Staddon, 1970b; 1972b).

In the case of frustration theory the requirement for the elicitation of unconditioned frustration by non-reward is that the stimulus conditions prevailing at the time of non-reward must be discriminated by the subject from those that normally accompany reinforcement. It is possible that omission of reinforcement on a constant probability VI schedule might not be discriminated sufficiently to result in frustration. However, if this were the case, frustration theory would suggest that reinforcement omission would have no effect on response strength. However, McMillan's (1971) finding of a longer pause following the omission stimuli than following reinforcement cannot be accounted for by frustration theory. Similarly, the present finding of a lower response rate in the early periods of those intervals initiated by the omission stimuli, compared to those intervals initiated by reinforcement, presents further difficulties for frustration theory, i.e., a form of 'negative' frustration. (Although the local response rates following reinforcement and following the omission stimuli both decreased during the reinforcement omission sessions, compared to the baseline sessions, there was a greater



decline in the rate in the early periods following the omission stimulus. It is possible that the general decline in responding was due to the lower reinforcement frequency encountered by the subjects during the omission sessions).

The present findings, are also at variance with Staddon's hypothesis regarding the after-effects of reinforcement on schedules of reinforcement. The decrease in the duration of the post omission pause, compared to the duration of the post-reinforcement pause, is consistent with the reinforcer having inhibitory after-effects on a constant probability VI schedule. As we have seen, this notion is difficult to incorporate into Staddon's hypothesis, however, the present findings of a lower local response rate in the early periods following the omission stimuli, compared to the same periods following reinforcement, presents even more difficulties. This finding is neither consistent with the reinforcer having inhibitory after-effects nor, as suggested by Staddon, with the reinforcer having essentially no after-effects on a constant probability VI schedule.

In summary, the results of the experiments reported in the present Chapter support, on the whole, the view that the reinforcer has inhibitory after-effects. In the

present experiments it was demonstrated that this is the case even on a schedule of reinforcement where there is an unchanging probability of reinforcement over time.

## CHAPTER 6

### ARITHMETIC VI SCHEDULES WITH ADDED SHORT INTERVALS

In Chapters 4 and 5 it was demonstrated that the reinforcing stimulus has inhibitory after-effects on both an arithmetic VI schedule and a constant probability VI schedule. However, the extent of the inhibitory after-effects differed between the schedules. To account for this it was suggested that the difference was related to the manner in which the probability of reinforcement varied over time on the two schedules. In the arithmetic VI schedule the occurrence of a reinforcer was followed by a period during which there was a low probability of

reinforcement, relative to the probability at longer post-reinforcement times. In the constant probability VI schedule, on the other hand, there was an approximately constant probability of reinforcement as a function of post-reinforcement time. Given this, the question arises as to whether or not the reinforcing stimulus will acquire inhibitory after-effects on a VI schedule which arranges so that the occurrence of a reinforcement is followed by a higher probability of reinforcement at short post-reinforcement times than at longer post-reinforcement times. That is, were the occurrence of a reinforcement signals a high probability of the next reinforcement occurring.

Staddon (1970b) has demonstrated that, under special circumstances, the reinforcing stimulus can acquire excitatory after-effects. He investigated the effects of omitting reinforcements on a schedule which developed a negatively accelerated response rate, i.e., a response-and-pause pattern of behaviour (also termed a Go-No-Go schedule). This schedule arranged so that pigeons key-pecking was reinforced on a VI schedule for approximately 1-min after reinforcement: for post-reinforcement times greater than 1-min reinforcement was obtained only by withholding key-pecking for at least 10-sec. This procedure generated a negatively accelerated response

rate, essentially a mirror image of the FI 'scallop'. When a 3-sec blackout was substituted for 50% of the reinforcements, the response rate following the blackout was substantially lower than the rate following reinforcement, although higher than the response rate following complete omission, i.e., when it was unsignalled. These results are the reverse of those found when reinforcements are omitted on an FI schedule (Kello, 1972; Staddon and Innis, 1966; 1969). Staddon (1972b) demonstrated that the above procedure could be used to produce either a respond-pause pattern of behaviour, i.e., Go-No-Go, or a pause-respond pattern, i.e., No-Go-Go (cf. FI schedules). He found that the effects of reinforcement omission were dependent upon the pattern of behaviour generated by each of the two schedules; on the Go-No-Go procedure he reported similar findings to those of Staddon (1970b), whereas on the No-Go-Go schedule the effects of reinforcement omission were essentially the same as those reported for FI schedules, e.g., Kello (1972).

In the present Chapter a VI schedule was investigated which arranged so that there was a higher relative probability of reinforcement at short post-reinforcement times than at intermediate post-reinforcement times (although reinforcement probability increased again at

longer post-reinforcement times). The occurrence of reinforcement, therefore, was followed by a high probability of reinforcement. The VI schedule studied was a modification of an arithmetic VI schedule, to include a high frequency of short-inter-reinforcement intervals and had a mean inter-reinforcement interval of 60-sec, (cf., Catania and Reynolds, 1968).

In the present Chapter two experiments will be reported, both of which used an arithmetic VI schedule with added short intervals. The experiments were concerned with the effects of (i) changes in the magnitude of the reinforcer, and (ii) the omitting of 50% of the scheduled reinforcements, upon the behaviour produced by the schedule.

## EXPERIMENT 5

### MANIPULATION OF THE MAGNITUDE OF REINFORCEMENT

#### METHOD

##### Subjects

Three naive male hooded rats (18, 19, and 20) served as subjects. They were housed and maintained as described in Chapter.3.

### Apparatus

The experimental boxes, scheduling and recording equipment were as described in Chapter 3. The arithmetic VI schedule with added short intervals was programmed in the same manner as in Experiment 1. The sequence of intervals used, in multiples of  $t$ , was 12, 1, 4, 13, 10, 1, 8, 11, 1, 14, 2, 1, 7, 14, 6, with  $t$  equal to 8.5-sec. This arranged for a mean inter-reinforcement interval of 60-sec. These represented the minimum times between successive reinforcements (cf. Experiment 1). Local response rates were collected using a bank of electromechanical counters operating in the same manner as described in Experiment 1.

### Procedure

#### Training

First the subjects were lever trained and then placed directly on the VI 60-sec schedule. The reinforcer was a 40% solution of Nestlé's condensed milk in water during this condition. The experiment was conducted daily until the subjects mean daily response rate over 5 successive sessions did not differ by more than  $\pm 10\%$  of the mean of the 5 sessions, (the numbers of sessions conducted were 70, 87 and 69 for the three subjects respectively). The first response in each session was followed by reinforcement,

and the VI schedule then operated, beginning at a different place in the series of intervals in successive sessions. Sessions ended after each interval in the series had occurred 4 times (61 reinforcements). The duration of each session was approximately one hour.

### Testing

The same schedule was in effect as in training. Four different reinforcer concentrations, 0% (water), 20%, 40% and 60% were presented in blocks of 5 reinforcements; the order of the blocks was random, with the constraint that, in a session, each block occurred 3 times. Three test sessions were conducted each consisting of 60 reinforcements. After this the subjects were returned to the baseline conditions with the 40% reinforcer concentration.

## RESULTS

The left hand panel of Figure 21 shows the median duration of the post-reinforcement pause as a function of reinforcement magnitude (see Table 7 for the interquartile ranges). For all the subjects the duration of the post-reinforcement pause was an increasing function of the



Figure 21. The median post-reinforcement pause (left panel), the mean running rate (centre panel), and the mean overall rate (right panel) as functions of the preceding reinforcer magnitudes. The unconnected points represent the baseline data. For each subject, data were taken from the last three baseline sessions and the three test sessions.

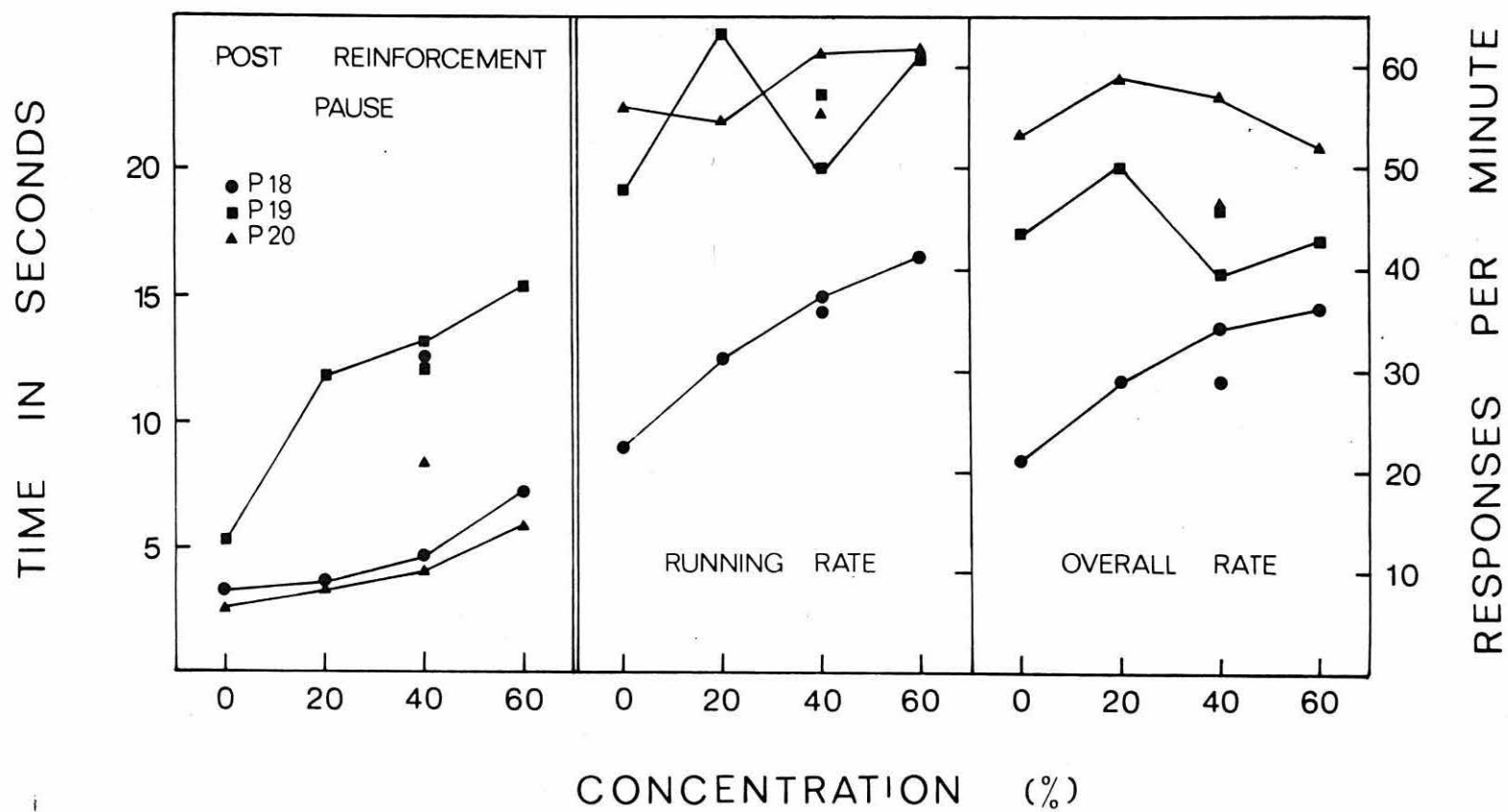


TABLE 7

The interquartile ranges of the post-reinforcement pause durations as a function of the preceeding reinforcer concentration. Data are from the last three baseline sessions and the three test sessions.

POST-REINFORCEMENT PAUSE IN SECONDS			
ANIMAL	CONCENTRATION	BASELINE	TEST
18	0%		2.4 - 3.9
	20%		3.0 - 4.3
	40%	11.0 - 14.0	3.9 - 5.7
	60%		5.9 - 8.9
19	0%		3.3 - 7.6
	20%		7.8 - 13.9
	40%	9.8 - 14.5	10.9 - 15.8
	60%		15.2 - 20.8
20	0%		2.0 - 3.4
	20%		2.6 - 4.0
	40%	7.0 - 9.8	3.4 - 4.9
	60%		5.0 - 7.4

magnitude of reinforcement, however, the extent of this function varied between subjects; for Subjects 18 and 20 the differences in the durations of the post-reinforcement pauses following the different concentrations were relatively small, i.e., approximately 1-sec, compared to the differences observed for Subject 19. Table 8 shows the mean post-reinforcement pause as a function of the ordinal position in a test block for the four concentrations; the duration of the post-reinforcement pause was not observed to vary systematically in relation to position in a test block.

The centre panel of Figure 21 shows the mean running rates following the different reinforcer magnitudes. In the cases of Subjects 19 and 20 the running rate was not systematically related to the magnitude of reinforcement. For Subject 19 rate increased from the 0% to the 20% concentration, decreased at the 40% reinforcer concentration, and then increased at the 60% concentration; for Subject 20 there was a slight decrease in rate from the 0% to the 20% concentration, followed by an increase at the 40% concentration and a further increase, although only slight, at the 60% concentration. In the case of Subject 18 the running rate was a positively increasing function of the reinforcer magnitude.

The functions found for the overall response rates following the different magnitudes of reinforcement (Figure

TABLE 8

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

		ORDINAL POSITION				
CONCENTRATION	ANIMAL	1	2	3	4	5
0%	18	3.8	3.8	3.2	2.8	3.7
	19	6.2	4.7	4.3	4.4	8.2
	20	3.6	3.0	2.3	2.6	3.2
	MEAN	4.5	3.8	3.3	3.3	5.0
20%	18	5.2	3.5	3.8	4.2	3.4
	19	14.6	12.4	11.2	11.4	11.9
	20	4.5	3.6	3.3	2.5	3.6
	MEAN	8.1	6.5	6.1	6.0	6.3
40%	18	5.1	5.3	5.2	4.6	4.5
	19	14.0	13.1	13.4	15.1	12.4
	20	4.4	4.3	4.2	4.2	4.2
	MEAN	7.8	7.6	7.6	8.0	7.0
60%	18	7.2	7.5	6.7	7.8	7.9
	19	17.9	17.2	18.6	21.8	16.9
	20	5.0	5.4	7.0	6.3	6.7
	MEAN	10.0	10.0	10.8	11.8	10.5

21, right hand panel), were similar, for Subjects 18 and 19, to those found for running rate. For Subject 20, however, the overall rate function differed from that observed for the running rate; the overall rate increased from the 0% to the 20% concentration but then decreased at the 40% and 60% concentrations. There was, therefore, little consistency between the subjects in the functions relating the overall and running response rates to the magnitude of reinforcement.

Figures 22, 23 and 24 show the local rates of responding for the last three baseline sessions and the three reinforcement magnitude sessions for the Subjects 18, 19 and 20 respectively. In the baseline sessions the local response rate, for Subjects 18 and 20, increased at short post-reinforcement times, decreased at intermediate times and then increased once again at the longer post-reinforcement times. In other words, for these Subjects the local response rate tended to change in relation to increases and decreases in the probability of reinforcement at different post-reinforcement times. In the case of Subject 19, however, the local response rate did not show these variations and was an almost monotonic function of the time elapsed since reinforcement.

In the sessions where the magnitude of the reinforcement was varied, for Subjects 19 and 20 the local rates of

Figure 22. The rates of responding following the different reinforcer magnitudes as functions of the time since reinforcement on an arithmetic VI 60-sec schedule with extra short intervals for Subject P18. Data are averages of the last three baseline sessions(B) and the three test sessions.

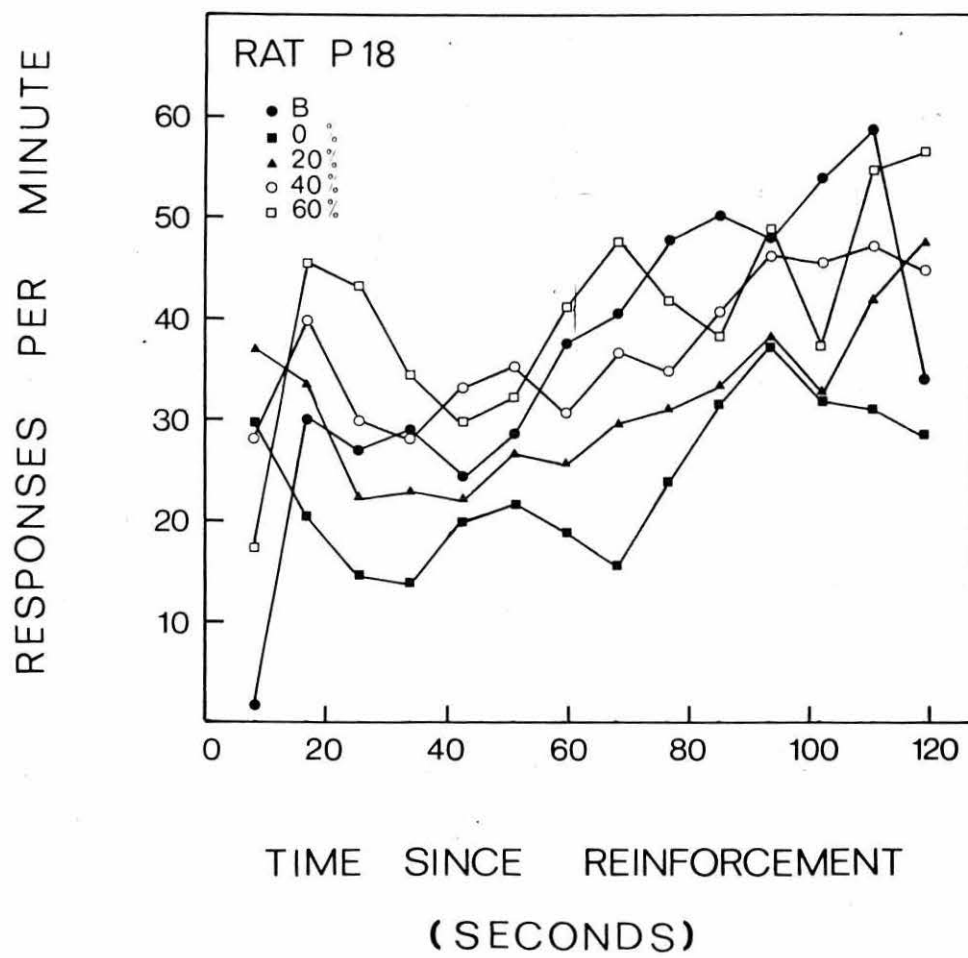




Figure 23. The rates of responding following the different reinforcer magnitudes as functions of the time since reinforcement on an arithmetic VI 60-sec schedule with extra short intervals for Subject P19. Data are averages of the last three baseline sessions (B) and the three test sessions.

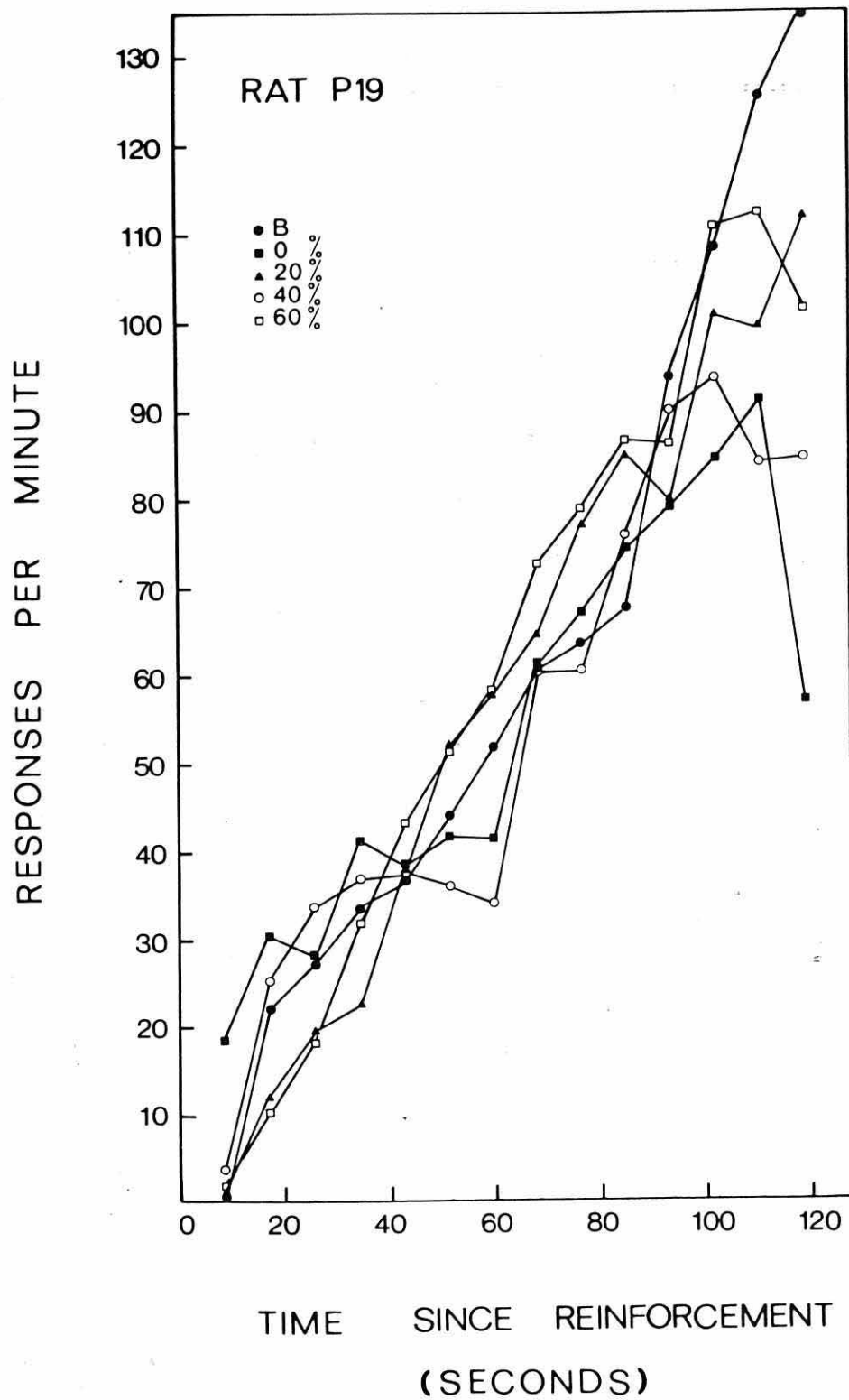
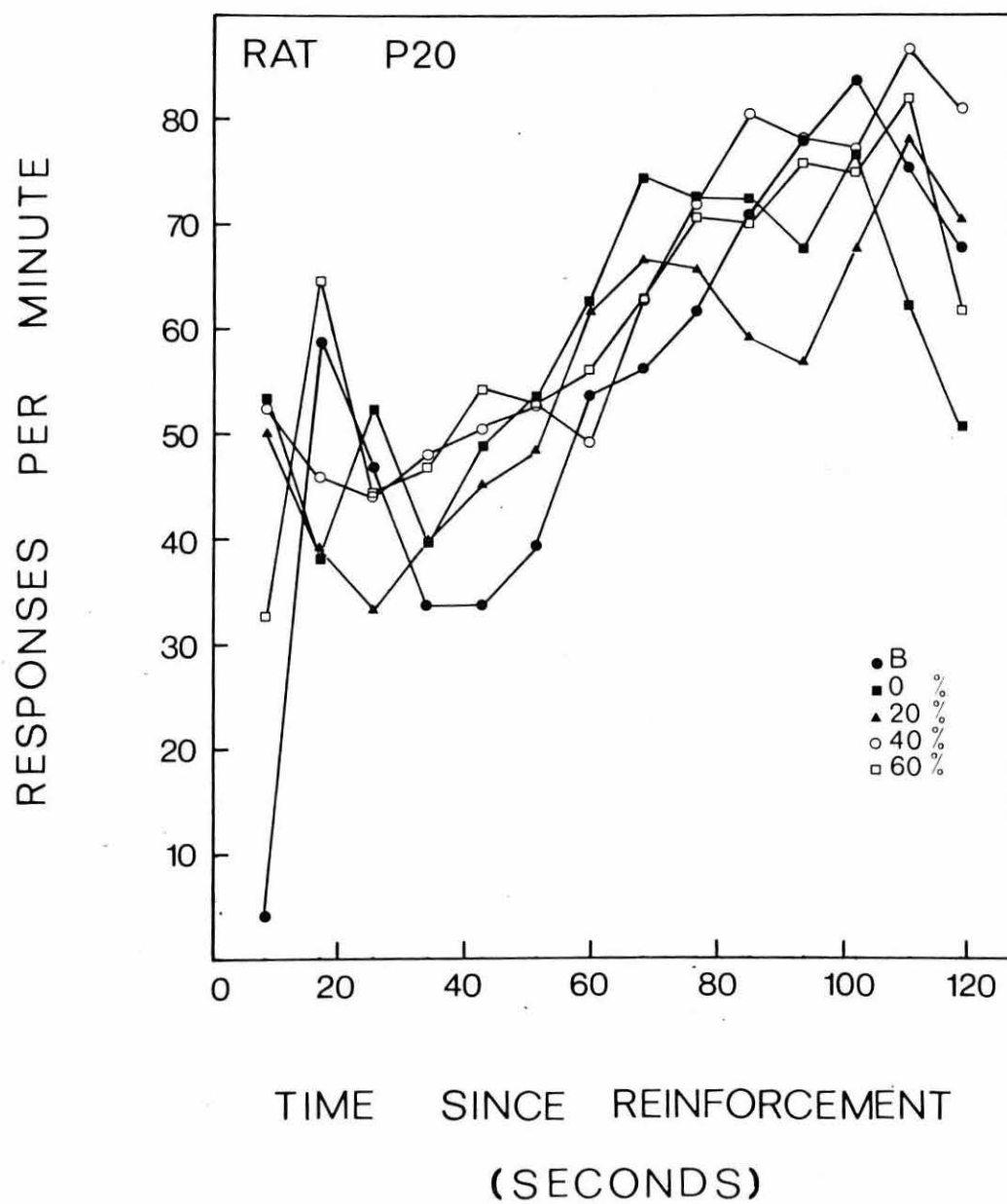


Figure 24. The rates of responding following the different reinforcer magnitudes as functions of the time since reinforcement on an arithmetic VI 60-sec schedule with extra short intervals for Subject P20. Data are averages of the last three baseline sessions (B) and the three test sessions.



responding were not systematically related to the magnitude of the reinforcement, however, the local rates varied over time in a similar manner as was observed in the baseline sessions. However, in the case of Subject 18 the local response rate was positively related to the reinforcement magnitude, i.e., although the local response rate functions following the different reinforcer magnitudes varied over time in a similar manner, there was a generally higher response rate following the greater magnitude of reinforcement.

## EXPERIMENT 6

### THE OMISSION OF REINFORCEMENT

#### METHOD

##### Subjects

Rats 18, 19 and 20 served as subjects. They had previous experience on an arithmetic VI schedule with added short intervals in Experiment 5. They were housed and maintained as described before.

### Apparatus

The experimental box, scheduling and recording equipment were the same as described in Experiment 5. The tone stimulus (with a frequency of 1000 Hz) was produced by directing the output of a frequency generator through an amplifier to a 6-inch 15 ohm speaker located on the lid of the experimental box. The intensity of the tone was approximately 85 db. The light stimulus was produced by 2 x 12 Watt 24V DC bulbs located on the front panel of the experimental box.

### Procedure

The subjects were maintained on the arithmetic VI 60-sec schedule with added short intervals, following Experiment 5. In addition each reinforcement presentation was accompanied by a 0.5-sec light/tone stimulus. The concentration of the milk reinforcer was kept at 40% throughout the experiment. All sessions were terminated after 61 reinforcements (cf. Experiment 5). A minimum of 25 daily sessions were conducted; and the subjects were judged to be stable when, after the 25th sessions, the response rate for any one of 5 consecutive sessions did not differ by more than  $\pm 10\%$  from the mean response rate over those 5 sessions (this was after 44, 30 and 40 sessions for the three subjects respectively). After this the

subjects were exposed to a procedure where 50% of the scheduled reinforcements were randomly omitted. Therefore, each completed inter-reinforcement interval ended in either reinforcement plus the stimuli or the stimuli alone. This reinforcement omission procedure was in effect for three sessions, after which the subjects were returned to the VI 60-sec schedule with 100% reinforcement presentation.

## RESULTS

Figures 25, 26 and 27 (upper panels) show, for Subjects 18, 19 and 20 respectively, the mean durations of the post-reinforcement and post-omission stimuli pauses for the last five baseline sessions, the three reinforcement omission sessions, and the first five return-to-baseline sessions. In all instances, the duration of the pause following the omission stimuli was considerably less than the duration of the post-reinforcement pause. In the reinforcement omission sessions, for Subjects 18 and 19, the duration of the post-reinforcement pause decreased compared to the baseline pause; in the return-to-baseline sessions there was an increase in the duration of the post-reinforcement pause, but they were of a shorter duration

Figure 25. The upper panel shows the mean durations of the post-reinforcement pause (filled circles) and the post omission stimuli pause (filled squares). The lower panel shows the running rates following reinforcement (filled circles) and following the omission stimuli (filled squares). The unconnected points represent the means of the baseline and return-to-baseline sessions. Data are from the last five baseline sessions (40-44), the three reinforcement omission sessions (45-47) and the first five return-to-baseline sessions (48-52) for Subject P18.



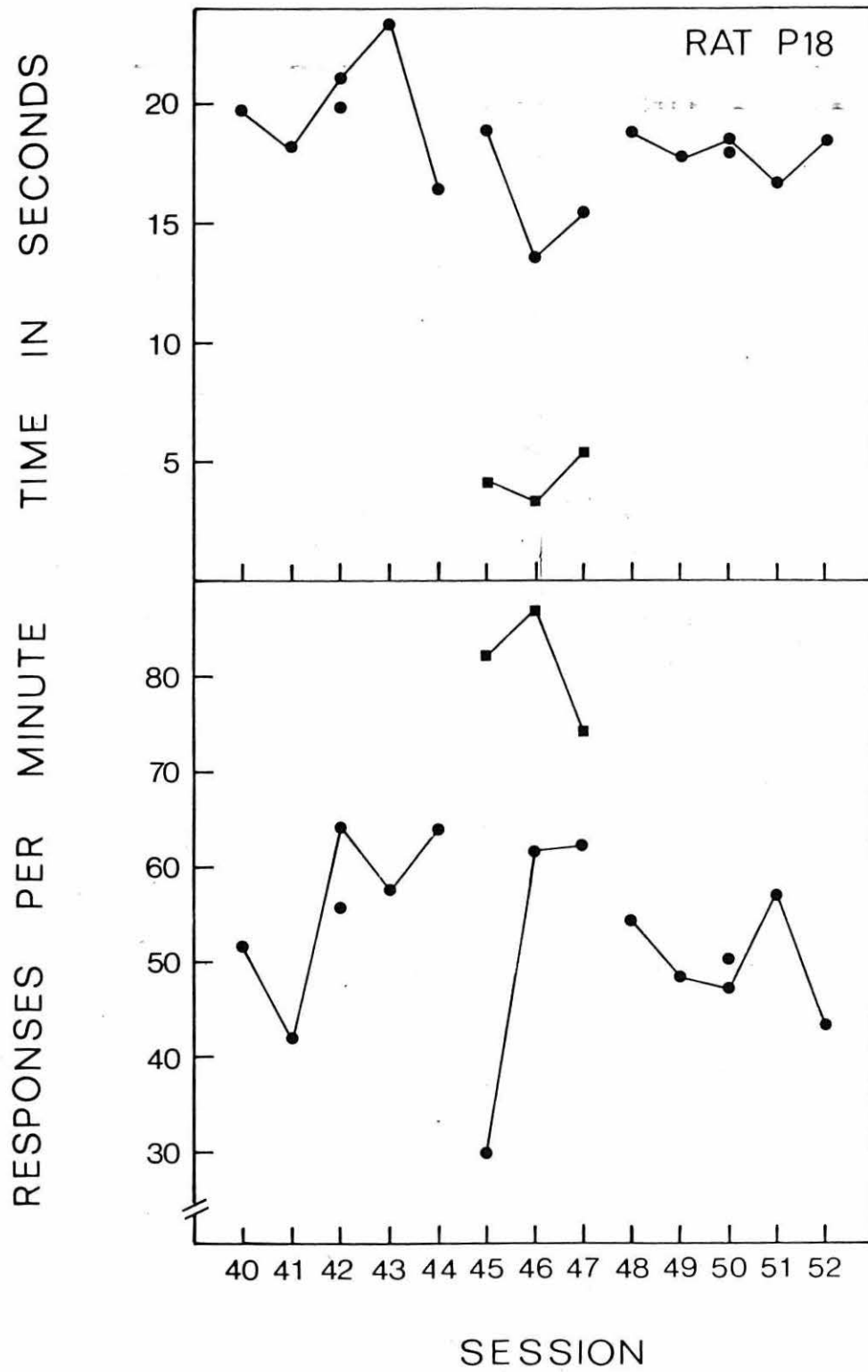


Figure 26. The upper panel shows the mean durations of the post-reinforcement pause (filled circles) and the post omission stimuli pause (filled squares). The lower panel shows the running rates following reinforcement (filled circles) and following the omission stimuli (filled squares). The unconnected points represent the means of the baseline and return-to-baseline sessions. Data are from the last five baseline sessions (26-30), the three reinforcement omission sessions (31-33) and the first five return-to-baseline sessions (34-38) for Subject P19.

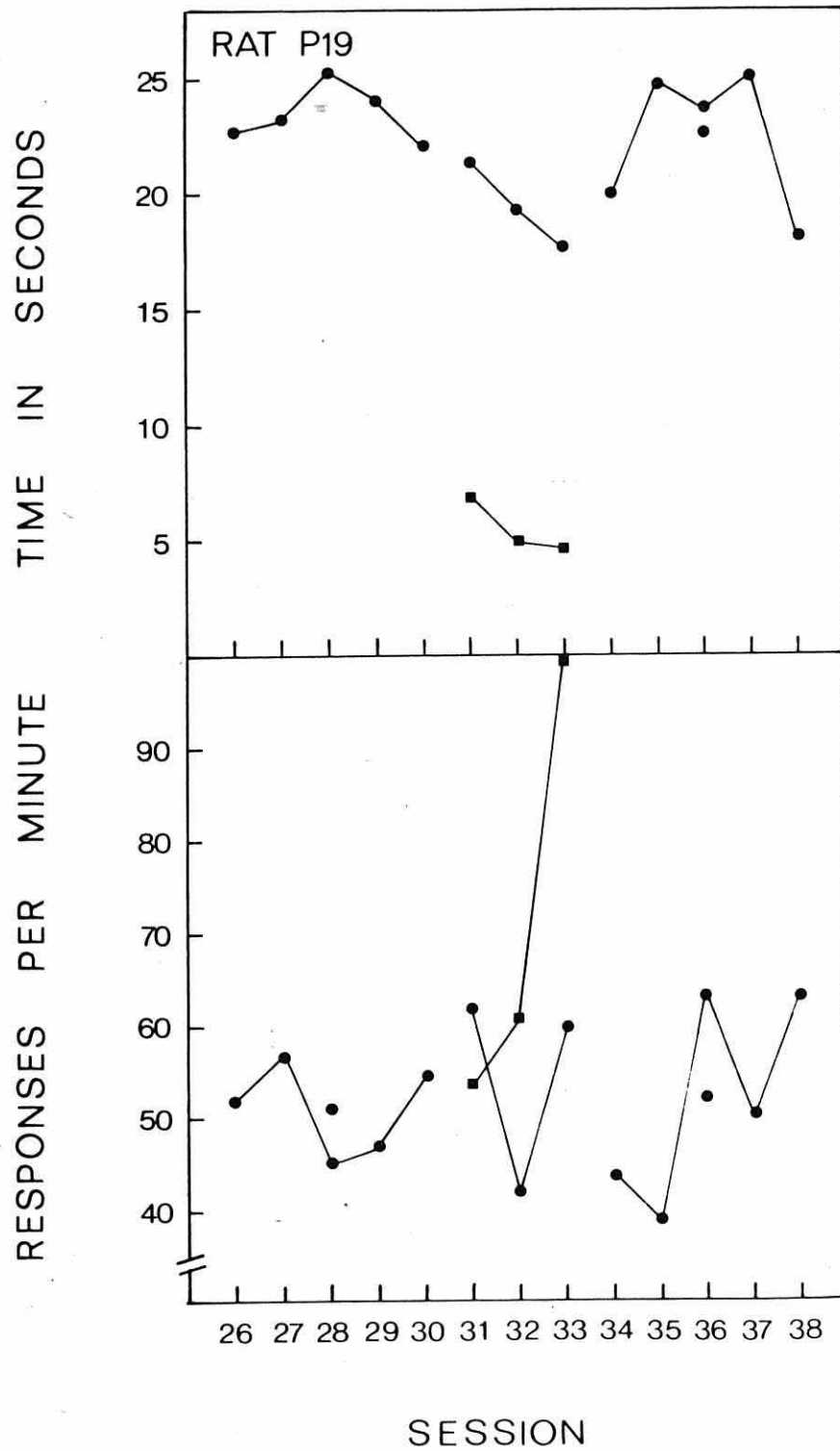
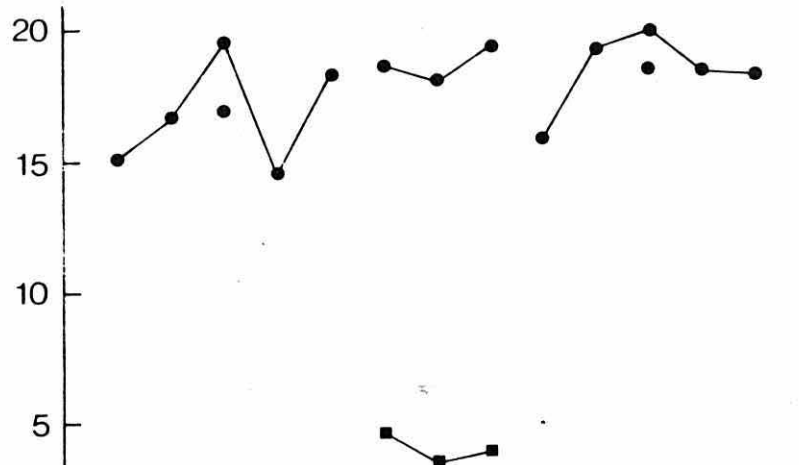


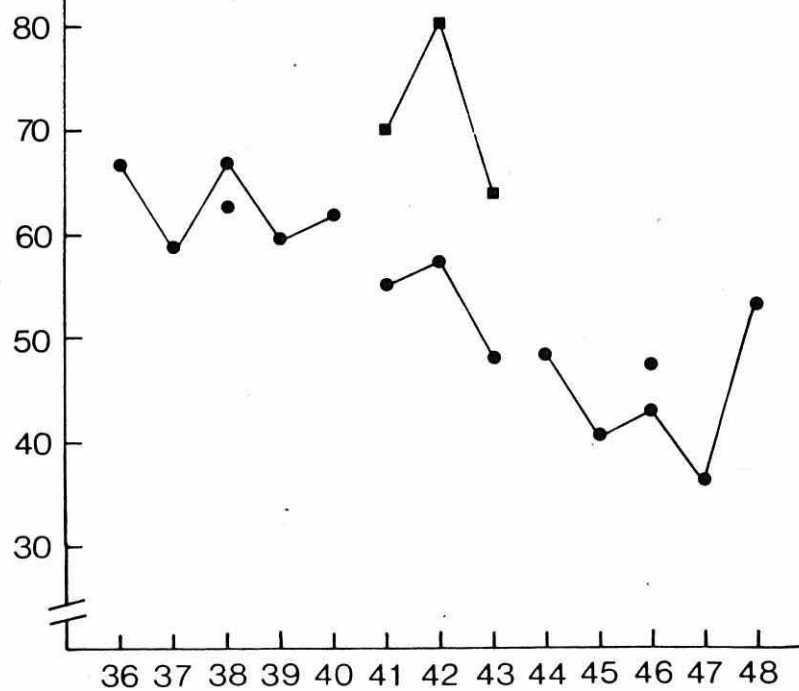
Figure 27. The upper panel shows the mean durations of the post-reinforcement pause (filled circles) and the post omission stimuli pause (filled squares). The lower panel shows the running rates following reinforcement (filled circles) and following the omission stimuli (filled squares). The unconnected points represent the means of the baseline and the return-to-baseline sessions. Data are from the last five baseline sessions (36-40), the three reinforcement omission sessions (41-43) and the first five return-to-baseline sessions for Subject P20

TIME IN SECONDS

RAT P20



RESPONSES PER MINUTE



SESSION

than the previous baseline post-reinforcement pauses. In the case of Subject 19 the post-reinforcement pause increased in the omission sessions, but decreased in the return-to-baseline sessions. However, pause duration was greater in the return-to-baseline sessions than in the previous baseline sessions.

Running rate (lower panels Figures 25, 26 and 27) was markedly higher following the omission stimuli than following reinforcement during the reinforcement omission sessions for all the Subjects, with the exception of the first omission session for Subject 19. For Subject 18 (Figure 25) running rate following reinforcement decreased markedly in the first omission session but recovered in the second and third sessions; running rate following the omission stimuli increased in the second omission session but decreased in the third session. The mean running rate over the five return-to-baseline sessions, for Subject 18 declined slightly compared to the mean of the five baseline sessions. For Subject 19 (Figure 26) running rate following reinforcement, during the omission sessions, decreased in the second omission session but recovered in the third session; rate following the omission stimuli was lower than the rate following reinforcement in the first omission session but

TABLE 9

Mean overall rate of responding. Data are from the last five baseline sessions, the three reinforcement omission sessions and the first five return-to-baseline sessions.

ANIMAL	BASELINE	OMISSION		RETURN-TO-
		FOLLOWING:		BASELINE
		REINFORCEMENT STIMULI		
18	38.7	37.6	75.3	40.0
19	32.1	37.2	64.2	33.4
20	47.8	36.2	67.2	33.5

increased sharply over the remaining sessions. There was little difference between the mean baseline and return-to-baseline running rates for Subject 19. In the case of Subject 20 (Figure 27) running rate following reinforcement, in the omission sessions, decreased in comparison to the running rate in the baseline sessions, and decreased further in the return-to-baseline sessions; rate following the omission stimuli increased in the second omission session but decreased in the third.

Similar effects were observed for the overall response rates in the baseline, reinforcement omission and return-to-baseline sessions for the three subjects (Table 9).

Figures 28, 29 and 30 show the mean local response rates for the last three baseline sessions and the three reinforcement omission sessions. In all instances, the local response rates following reinforcement both in the baseline and in the reinforcement omission sessions, were a monotonic function of the time elapsed since reinforcement (cf. Experiment 5). Also, in all instances the local response rates following the omission stimuli was very much higher than the rates following reinforcement. This difference in local rates was very marked and disappeared only at the longer post-reinforcement or post-omission times.



Figure 28. The rates of responding as functions of the time since reinforcement in the baseline (filled circles) and the reinforcement omission sessions (filled squares), also, the rate of responding as a function of the time since the omission stimuli (filled triangles) for Subject Pl8. Data are averages of the last three baseline sessions and the three reinforcement omission sessions.

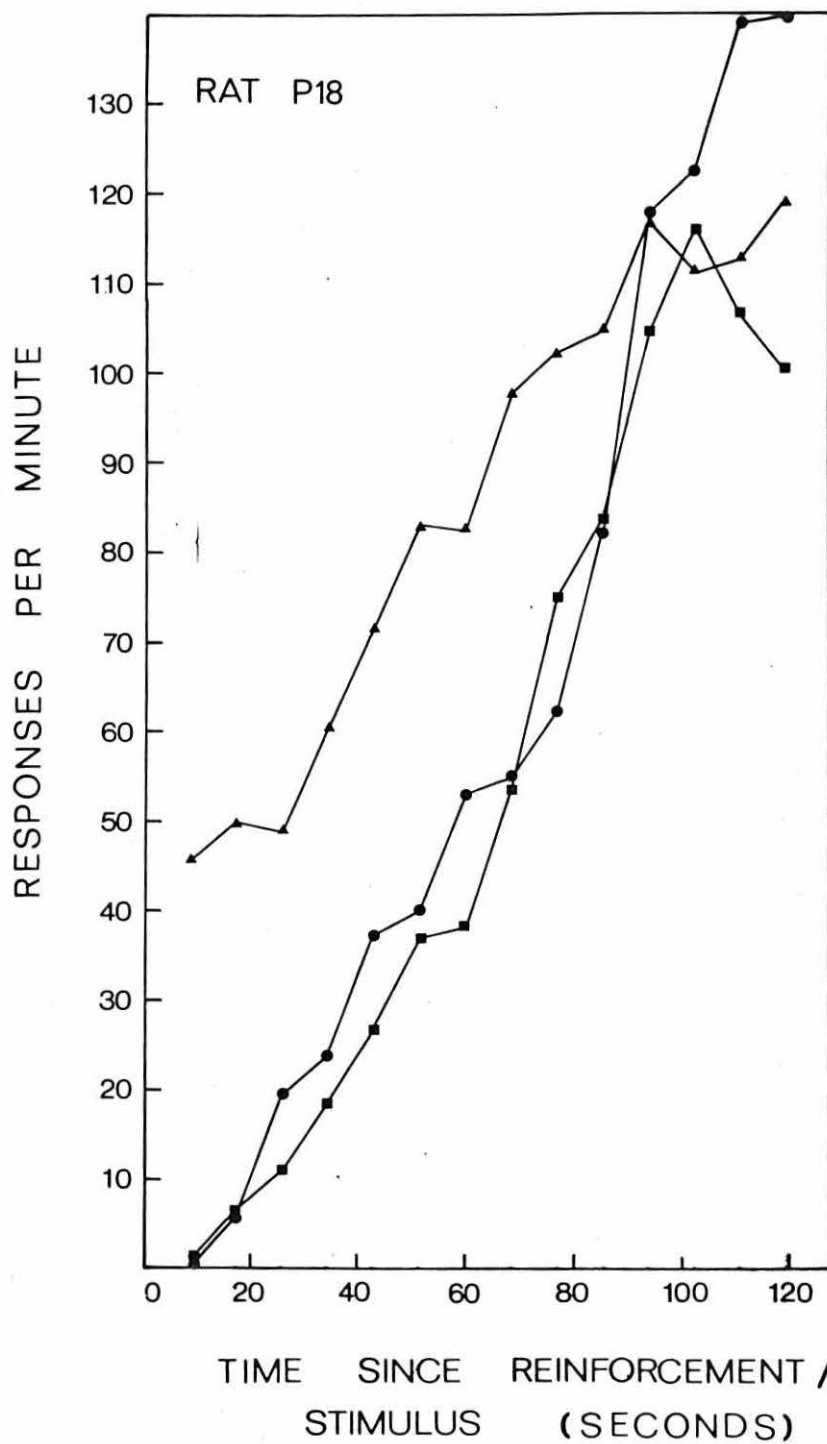


Figure 29. The rates of responding as functions of the time since reinforcement in the baseline (filled circles) and the reinforcement omission sessions (filled squares), also, the rate of responding as a function of the time since the omission stimuli (filled triangles) for Subject P19. Data are averages of the last three baseline sessions and the three reinforcement omission sessions.

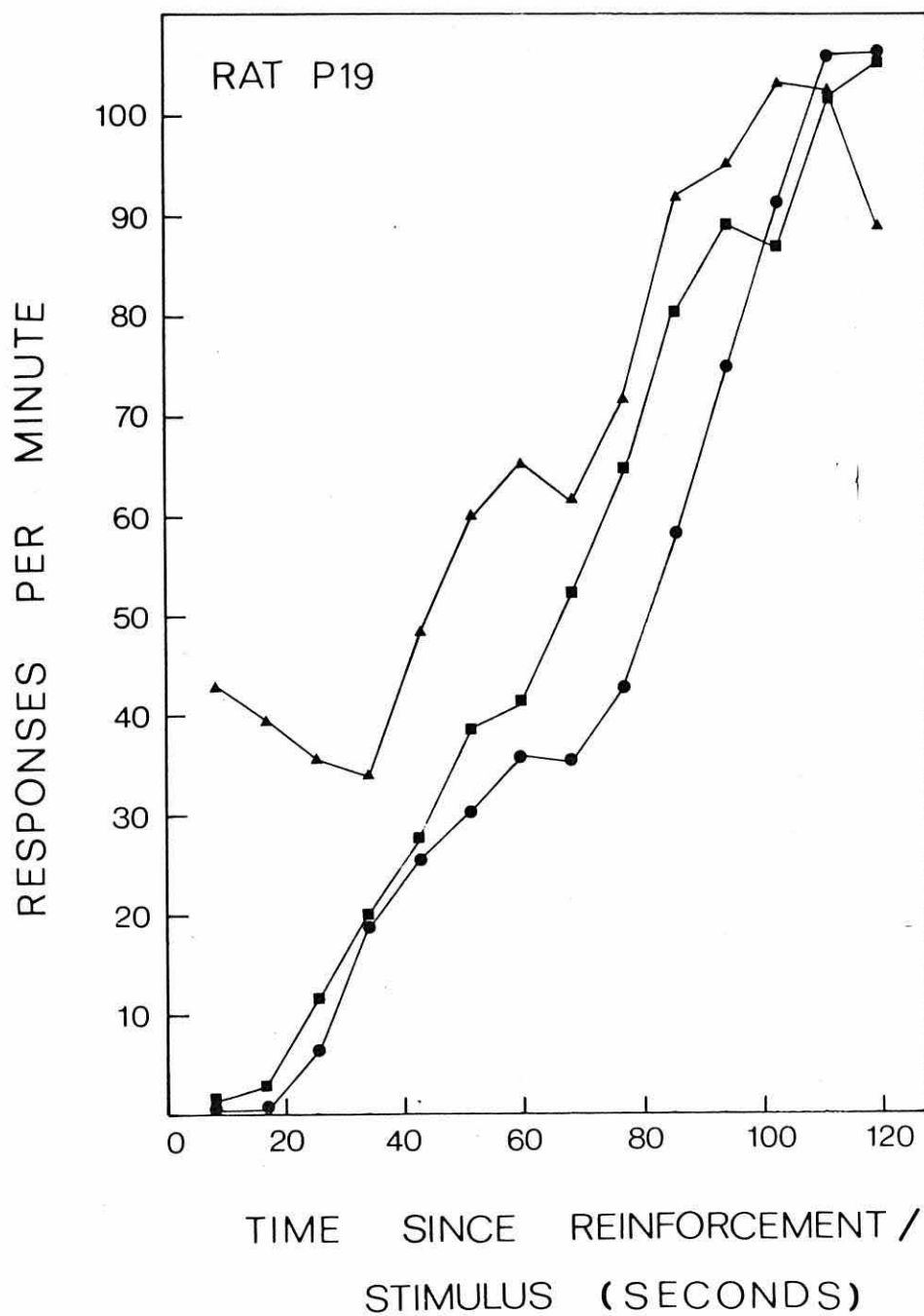
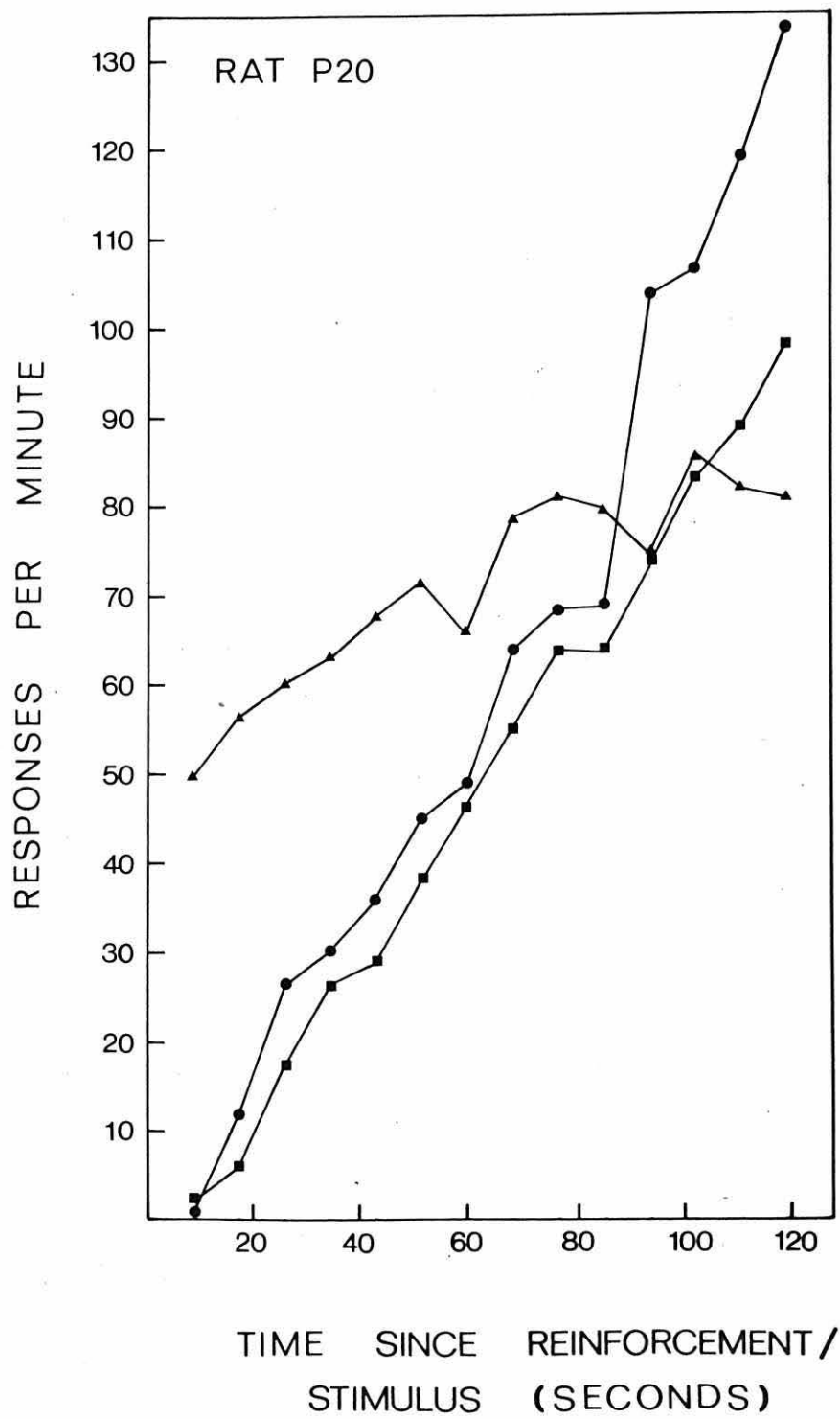


Figure 30. The rates of responding as functions of the time since reinforcement in the baseline (filled circles) and the reinforcement omission sessions (filled squares), also, the rate of responding as a function of the time since the omission stimuli (filled triangles) for Subject P20. Data are averages of the last three baseline sessions and the three reinforcement omission sessions.



## GENERAL DISCUSSION

The results of both of the present experiments indicate that the reinforcing stimulus acquired inhibitory after-effects on an arithmetic VI schedule with a high frequency of short intervals.

It has been argued in this thesis that the changes observed in the duration of the post-reinforcement pause, on a schedule of reinforcement, consequent to the magnitude of the reinforcer being increased, provide an indication as to the nature of the after-effects, if any, acquired by the reinforcing stimulus in that situation. In Experiment 5 it was found that the duration of the post-reinforcement pause was a positive function of the magnitude of reinforcement. This finding is consistent with those reported for other schedules, for example, FI schedules (Jensen and Fallon, 1973; Lowe et al., 1974; Staddon, 1970a) and FR schedules (Lowe et al., 1974). Also, it is consistent with the notion that the reinforcing stimulus acquired inhibitory after-effects on the schedule investigated in the present Experiment. Overall and running response rates, on the other hand, did not show any consistent changes with variations in the magnitude of reinforcement.

Similarly, the results of Experiment 6 where 50% of the scheduled reinforcements were omitted and a 'neutral' stimulus was presented in lieu of reinforcement provide further support for the notion that the reinforcer acquired inhibitory after-effects. It was found, during reinforcement omission, that the duration of the pause following the omission stimuli was considerably less than the duration of the post-reinforcement pause. That is, there was a reduction in the after-effects following the omission stimuli compared to those following reinforcement. This finding is consistent with those reported, consequent to reinforcement omission, on other schedules, for example, FI schedules (Kello, 1972; Staddon and Innis, 1966; 1969). The results of the present study do, however, differ from those in one major respect. Generally, on most schedules, reinforcement omission has its principal effect upon the pause following the omission stimulus and does not, to any great extent, effect the running response rates following reinforcement and following the omission stimulus. In the present study there was a marked increase in the running rate following the omission stimuli relative to the rate following reinforcement. Also, the local response rate data revealed that this increase occurred immediately following the occurrence of the omission stimuli and only disappeared at the longer post-omission times, i.e., the effect was persistent.



With regard to the theoretical interpretations of the reinforcement omission effect, the results of the present study are consistent with either a 'frustration' account or with Staddon's generalization of the after-effects of reinforcement hypothesis.

Elsewhere in this thesis it has been argued that if, on a schedule of reinforcement, the occurrence of a reinforcer is followed by a low or zero probability of reinforcement then this is a sufficient condition for the reinforcer to acquire inhibitory after-effects. Given this, in the present study, owing to the fact that the distribution of inter-reinforcement intervals included a high frequency of short intervals, the occurrence of a reinforcer was followed by a relatively high probability at short post-reinforcement times of the next reinforcement occurring. It might be expected, therefore, that the reinforcer would develop excitatory after-effects on such a schedule. In view of this argument it is not clear why the reinforcer acquired such marked inhibitory after-effects in the present study. Nevertheless, the added short-intervals did have some effect upon behaviour. In Experiment 5, for two of the three Subjects, there was a tendency for the local response rate to vary in relation to the local variations in reinforcement probability (cf. Catania and Reynolds, 1968). However, for the third

subject in Experiment 5, and for all three subjects in Experiment 6, the local response rates did show any systematic variation as a function of post-reinforcement time.

In summary, the results of the present experiments indicate that local variations in the probability of reinforcement are not in themselves sufficient to overcome what would appear to be the tendency for the reinforcing stimulus, on most schedules of reinforcement, to develop inhibitory after-effects.

## CHAPTER 7

### VARIABLE-RATIO SCHEDULES OF REINFORCEMENT

It has been argued in this thesis that, on some schedules of reinforcement, the reinforcing stimulus has inhibitory after-effects. According to Ferster and Skinner (1957), for example, the reinforcer on fixed-interval schedules controls a pause (the post-reinforcement pause) because it signals a period in which reinforcement is not available. Evidence in support of this position comes from studies which have shown that the duration of the post-reinforcement pause on FI schedules is a positive

linear function of the interval specified by the schedule (Sherman, 1959; Schneider, 1969). It has also been shown that the inhibitory after-effects of reinforcement on FI schedules are enhanced when the magnitude of reinforcement is increased (Jensen and Fallon, 1973; Lowe et al., 1974; Staddon, 1970) and several studies have demonstrated that when reinforcement is on some occasions omitted and replaced by a 'neutral' stimulus, the duration of the pause after the stimulus is considerably less than the pause after reinforcement (Kello, 1972; Staddon and Innis, 1966; 1969).

In the case of the FR schedule, Ferster and Skinner (1957) indicated that the reinforcer may also have temporal inhibitory after-effects, as, after reinforcement a response cannot be reinforced within a shorter period of time than that required to count out the ratio. The duration of the post-reinforcement pause on FR schedules is a function of the number of responses required by the schedule (Boren, 1961; Felton and Lyon, 1966; Powell, 1968) and several studies indicate that it is the time taken to emit the responses in the ratio that governs the duration of the post-reinforcement pause (Berryman and Nevin, 1962; Killeen, 1969; Neuringer and Schneider, 1968). The notion that the reinforcer on FR schedules has inhibitory after-effects is further strengthened by the findings (i)

that the duration of the post-reinforcement pause is directly related to the magnitude of the preceding reinforcer (Lowe et al., 1974) and (ii) that there is a marked reduction in pausing following a stimulus presented in lieu of a scheduled reinforcer (McMillan, 1971).

The question, however, of whether reinforcement has inhibitory after-effects on variable-ratio (VR) reinforcement schedules remains to be explored. On VR schedules reinforcement occurs after a given number of responses, the number varying from reinforcement to reinforcement (Ferster and Skinner, 1957). These usually take the form of arithmetically or geometrically distributed sequences of responses with a specified mean value or, alternatively, the schedule value is defined in terms of a constant probability of reinforcement for each response, the latter usually being referred to as random ratio schedules. Given that time is taken up in meeting the ratio requirement on either VR or RR schedules, there would appear to be a basis for the reinforcer acquiring inhibitory after-effects. According to this account, as the ratio requirement is increased, and presumably the time taken to meet the requirement, the post-reinforcement pause should also increase. There is some evidence to support this: Farmer and Schoenfeld (1967) found that the duration of the post-reinforcement

pause on a RR schedule increased as the probability of reinforcement was decreased. Similarly, if the reinforcer acquires inhibitory after-effects on a VR schedule these should be enhanced when the magnitude of the reinforcer is increased and should be absent when the reinforcer is omitted.

## EXPERIMENT 7

The present experiment was designed to investigate the inhibitory effects of reinforcement on VR schedules when, (i) schedule value and, (ii) magnitude of reinforcement are varied.

## METHOD

### Subjects

Four naive male hooded rats (1, 2, 3, and 4) served as subjects. They were housed individually and maintained at 80% of their free-feeding weights throughout the experiment. Water was freely available in the home cages.

### Apparatus

The experimental boxes and scheduling equipment were the same as described in Chapter 3. The data were collected

TABLE 10

The sequence of variable ratio requirements used in each schedule.

Schedule	Sequence of ratios (left of right)									
VR 10	16	<b>1</b>	10	14	7	12	2	8	13	4
	10	7	8	19	16	3	11	5	9	14
	18	4	18	5	9	17	15	6	15	19
	4	1	2	6	11	13	12	17		
VR 40	64	4	40	56	28	48	8	32	52	12
	40	28	32	76	64	12	44	20	36	56
	72	16	72	20	36	68	60	24	60	76
	16	4	8	24	44	52	48	68		
VR 80	128	8	80	112	56	96	16	64	104	24
	80	56	64	152	128	24	88	40	72	112
	144	32	144	40	72	136	120	48	120	152
	32	8	16	48	88	104	96	136		

and analysed using a Data General Corporation Nova 1200 computer.

### Procedure

All subjects were lever trained and then placed on a VR 80 schedule (the sequence of ratios is shown in Table 10 ). Sessions were conducted daily and each session was terminated in all instances after 77 reinforcements. During these sessions the reinforcer was a 30% solution of condensed milk. The behaviour was judged to be stable when, after the 30th session, the response rate for any one of five consecutive sessions did not differ by more than 10% from the mean response rate over those five sessions. The subjects were then tested with four different reinforcer concentrations, 10%, 30%, 50% and 70%. These were presented randomly within each session with the constraint that no single concentration could occur more than three times in sequence. Four test sessions were conducted each consisting of 77 reinforcements.

The above procedure was then repeated with two further VR values, VR 10 and VR 40, in that order.



## RESULTS

Figure 31 shows for each subject median post-reinforcement pause and running rate as a function of the preceding reinforcer concentration, on the three ratio values (inter-quartile ranges are presented in Tables 11 and 12 ). The duration of the post-reinforcement pause increased as a function of reinforcement magnitude for all subjects, at each of the ratio values. Running rate did not show any systematic relationship with reinforcement magnitude. The left panel of Figure 32 shows the mean post-reinforcement pause, over all four subjects, as a function of the reinforcer concentration on each of the three schedules. Not only was the duration of post-reinforcement pause positively related to the magnitude of the reinforcer, but the extent to which this was the case was dependent upon the schedule value; the higher the VR value the greater was the increase in post-reinforcement pause duration. The effect of schedule value is also seen in the running rates (centre panel Figure 32); this shows on all reinforcement concentrations that running rate decreased as the schedule value was increased. Overall response rate declined as a function of reinforcement magnitude, this decline reflecting mainly the effect of reinforcement magnitude upon post-reinforcement pause duration. Over all concentrations the overall rate was higher on the VR 40 and VR 80 schedules (the overall rates for the individual subjects are shown in Table 13).

Figure 31. Median post-reinforcement pause (upper section) and running rate (lower section) as functions of concentration of the preceding reinforcement for VR 10 (left panel), VR 40 (centre panel), and VR 80 (right panel). Data were averaged across the test sessions for each of the four subjects.

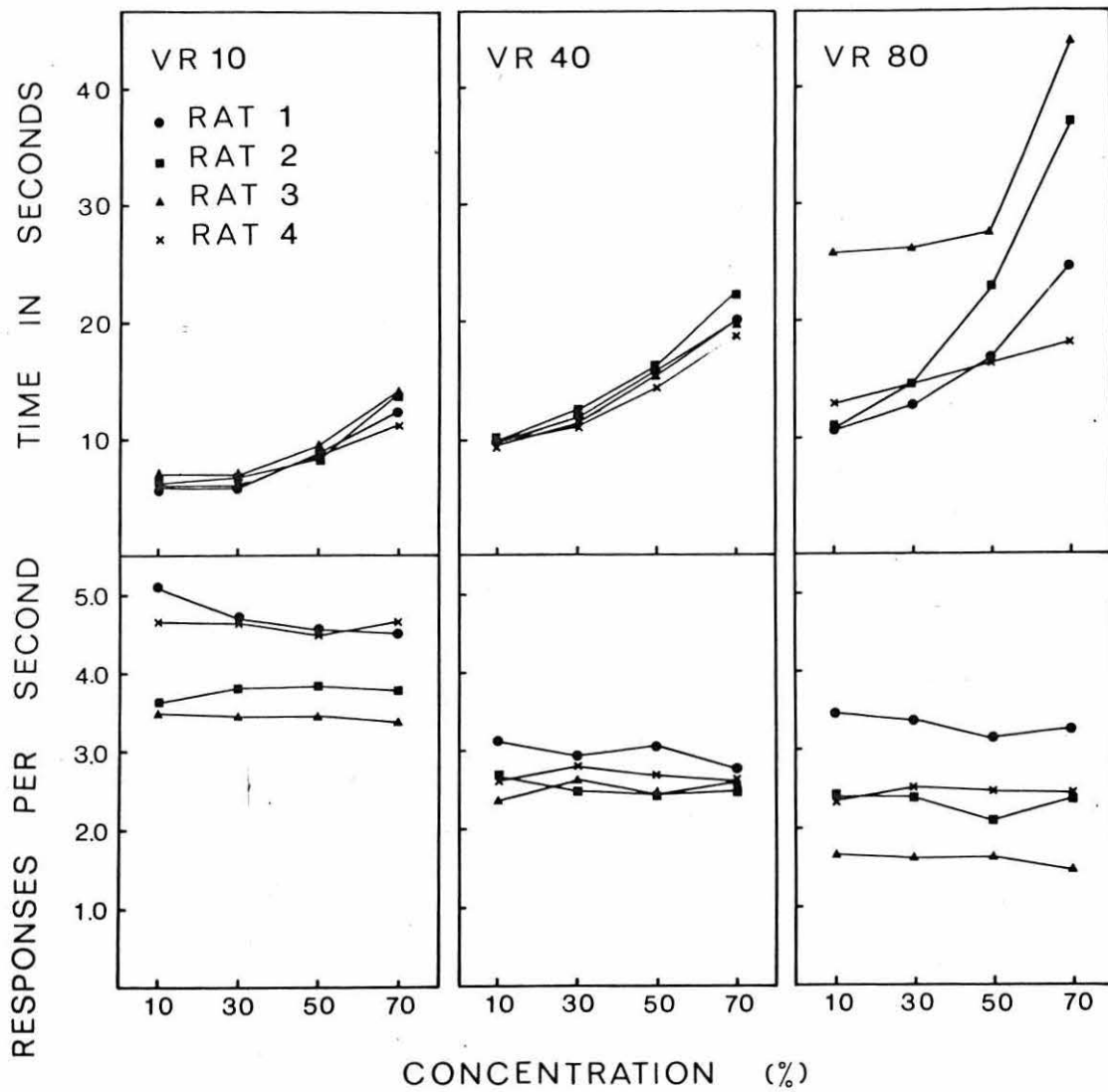


TABLE 11

The interquartile ranges of the duration of post-reinforcement pauses following each reinforcer concentration, on each schedule.

ANIMAL	CONCENTRATION	VR 10		VR 40		VR 80	
		Post-reinforcement pause in seconds		Post-reinforcement pause in seconds		Post-reinforcement pause in seconds	
		BASELINE	TEST	BASELINE	TEST	BASELINE	TEST
1	10%		3.9 - 7.4		8.2 - 11.8		8.8 - 13.4
	30%		4.6 - 7.4		10.2 - 13.7		10.3 - 15.8
	50%	8.1 - 10.0	6.9 - 10.0	9.8 - 11.9	12.5 - 19.7	16.3 - 22.0	14.3 - 21.2
	70%		9.5 - 13.5		14.4 - 27.2		20.3 - 29.1
2	10%		5.1 - 8.4		8.8 - 11.3		8.7 - 17.3
	30%		5.5 - 8.0		10.4 - 13.7		12.2 - 19.6
	50%	6.7 - 9.1	6.8 - 9.9	9.8 - 12.2	13.0 - 21.4	8.2 - 17.2	18.2 - 33.9
	70%		9.7 - 17.8		19.2 - 27.8		30.7 - 59.0
3	10%		5.6 - 10.0		8.2 - 11.1		14.4 - 29.9
	30%		6.1 - 7.6		9.9 - 13.6		16.8 - 31.6
	50%	6.8 - 9.0	8.1 - 11.6	7.1 - 9.7	12.8 - 19.3	9.9 - 20.8	16.6 - 37.6
	70%		12.0 - 15.5		18.0 - 26.5		32.6 - 53.8
4	10%		4.9 - 7.8		8.3 - 11.4		10.4 - 17.8
	30%		4.9 - 8.2		9.4 - 13.1		12.6 - 19.4
	50%	6.9 - 9.8	7.1 - 11.3	8.0 - 9.8	11.7 - 17.2	12.2 - 19.7	14.3 - 21.3
	70%		8.2 - 14.3		16.4 - 21.8		16.3 - 25.4

TABLE 12

The interquartile ranges of the running rates of responses following each concentration, on each schedule.

ANIMAL	CONCENTRATION	VR 10		VR 40		VR 80	
		Running rate (responses per second)		Running rate (responses per second)		Running rate (responses per second)	
		BASELINE	TEST	BASELINE	TEST	BASELINE	TEST
1	10%		3.69 - 6.35		2.41 - 3.62		2.98 - 3.91
	30%		3.69 - 5.58		2.41 - 3.51		2.89 - 3.76
	50%	5.38 - 4.90	3.75 - 5.50	2.29 - 3.42	2.38 - 3.59	3.03 - 3.76	2.53 - 3.63
	70%		3.44 - 5.04		2.11 - 3.44		2.66 - 3.68
2	10%		3.05 - 4.29		2.33 - 3.19		2.05 - 2.72
	30%		3.33 - 4.51		2.21 - 2.99		2.05 - 2.72
	50%	2.78 - 4.19	3.12 - 4.55	2.22 - 2.92	2.11 - 3.02	2.13 - 2.85	1.45 - 2.58
	70%		3.24 - 4.48		2.18 - 2.99		1.92 - 2.77
3	10%		2.86 - 4.07		2.05 - 2.88		1.27 - 2.11
	30%		2.75 - 3.95		2.24 - 3.00		1.26 - 1.95
	50%	2.27 - 3.79	2.72 - 4.12	2.22 - 2.94	2.10 - 2.81	1.53 - 2.62	1.24 - 1.98
	70%		2.62 - 3.95		2.15 - 3.09		1.21 - 1.93
4	10%		4.13 - 5.63		2.22 - 3.06		1.95 - 2.69
	30%		4.01 - 5.36		2.35 - 3.47		2.21 - 2.79
	50%	4.04 - 5.29	4.06 - 5.40	2.23 - 3.09	2.23 - 3.33	2.09 - 2.79	2.24 - 2.82
	70%		4.16 - 5.30		2.25 - 2.97		2.08 - 2.79

Figure 32. Mean post-reinforcement pause (left panel), running rate (centre panel), and overall rate (right panel) as functions of concentration of the preceding reinforcement for the VR 10, VR 40, and VR 80 schedules. Data were averaged across the test sessions for the four subjects on each schedule.

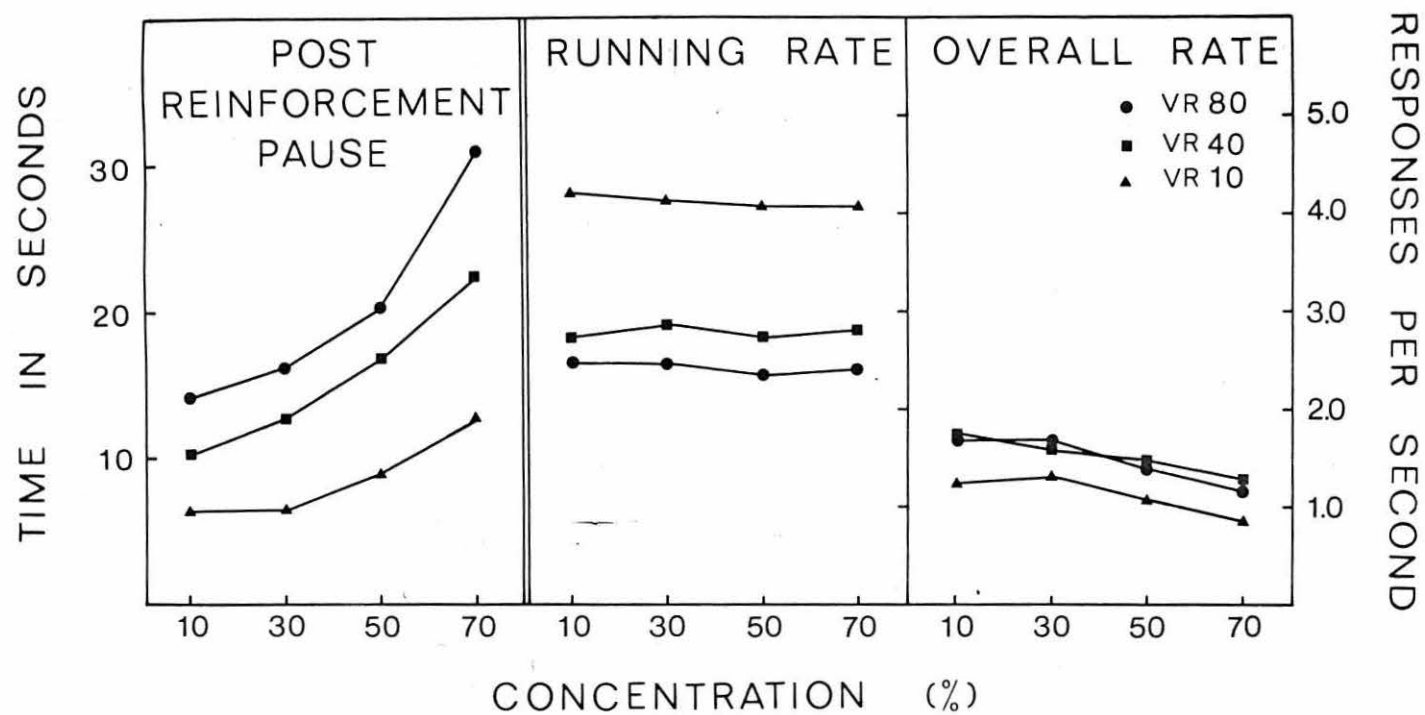


TABLE 13

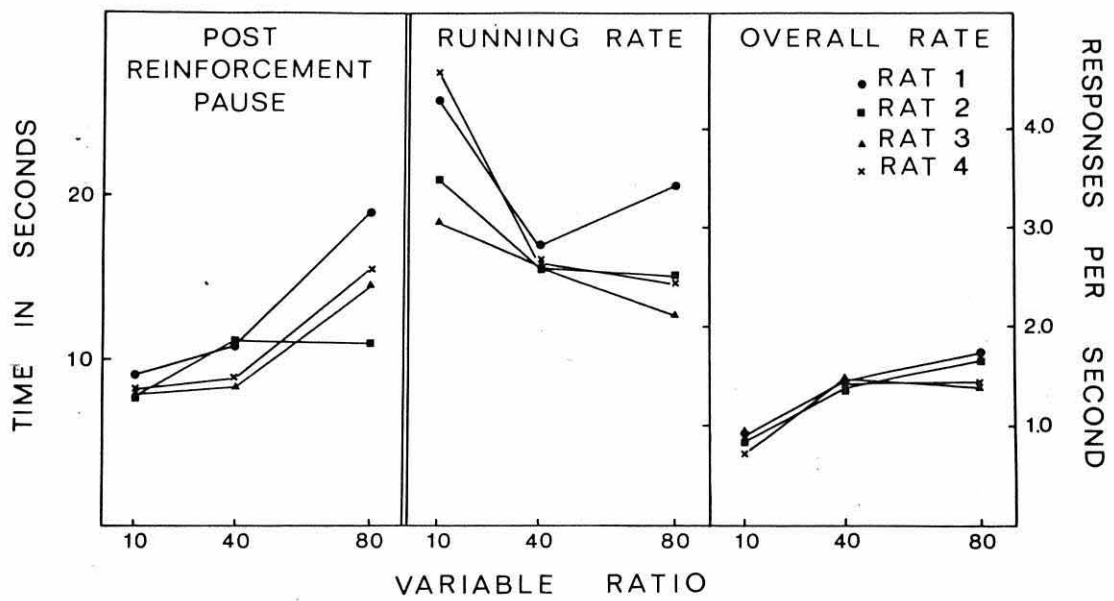
Overall response rates following each concentration on each schedule.

ANIMAL	CONCENTRATION	SCHEDULE		
		VR10	VR40	VR80
1	10%	1.17	1.75	2.41
	30%	1.61	1.92	2.10
	50%	1.12	1.49	2.01
	70%	1.09	1.08	1.69
2	10%	0.94	1.69	1.70
	30%	1.14	1.49	1.52
	50%	1.13	1.32	1.24
	70%	0.66	1.08	1.08
3	10%	0.83	1.59	1.20
	30%	1.09	1.57	1.05
	50%	0.88	1.30	1.01
	70%	0.73	1.18	0.86
4	10%	1.39	1.68	1.63
	30%	1.36	1.68	1.66
	50%	1.12	1.43	1.52
	70%	0.90	1.26	1.52



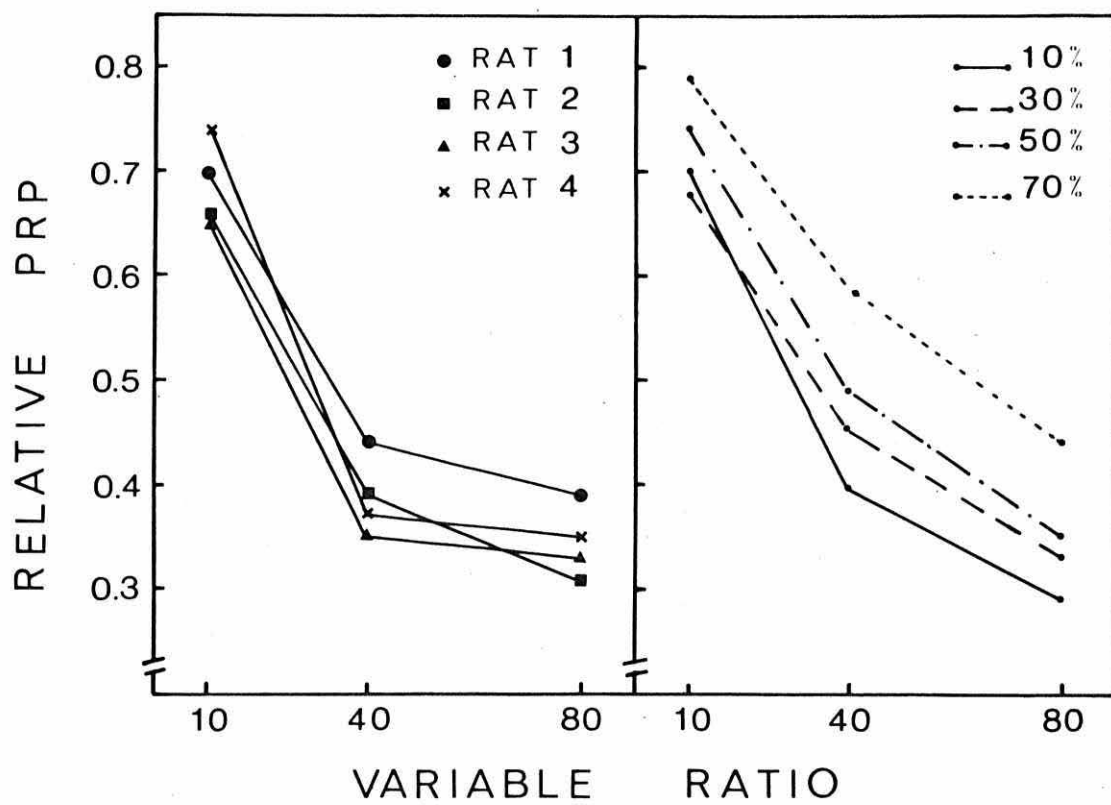
Baseline data from the last three sessions, before reinforcement magnitude testing, on each VR schedule are shown in Figure 33. . The left panel shows that median post-reinforcement pause duration increased as the VR value increased in all instances, with the exception of Subject 4 which shows a slight decline on VR 80. (See Table 11 for inter-quartile ranges). For all subjects, running rate showed a marked decline between the VR 10 and VR 40 schedules; there was a further decline between the VR 40 and VR 80 schedules for three of the four subjects, Subject 1 showing an increase on the VR 80 schedule. Overall response rate increased for all subjects from the VR 10 to the VR 40 schedule and for Subjects 1 and 2 increased further on the VR 80 schedule; overall rates for Subjects 3 and 4 shows little difference between the VR 40 and VR 80 schedules. There is an apparant anomaly in the data presented in Figure 33. On the one hand, while the duration of the post-reinforcement pause increased and running rate decreased as a function of VR value, overall response rate increased with increasing ratio value. This anomaly is resolved if the post-reinforcement pause is considered as a proportion of the mean inter-reinforcement interval (the relative post-reinforcement pause). The left panel of Figure 34 shows that for all subjects the relative post-reinforcement pause decreased as a function of schedule value: although as it was shown in Figure 33 the absolute duration of the post-reinforcement pause increased with

Figure 33. Median post-reinforcement pause (left panel), running rate (centre panel), and overall rate (right panel) as a function of the VR schedule value. Data were averaged across the last three baseline sessions for each of the four subjects.



increases in the ratio value. It would thus appear that the increase in overall response rate as a function of schedule value was largely a consequence of a relatively shorter post-reinforcement pause, even though this was accompanied by a decline in running rate. The right hand panel of Figure 34 shows the mean relative post-reinforcement pause for all the subjects over the four different reinforcer concentrations; in all instances there was a decline with increasing schedule value. On each of the VR schedules the relative post-reinforcement pause was directly related to the magnitude of reinforcement, the only exception to this being the 10% and 30% data points which cross over on the VR 10 schedule.

Figure 34. Post-reinforcement pause proportional to the inter-reinforcement interval as a function of ratio value for each of the four subjects, and mean relative post-reinforcement pause for all the subjects on each of the concentrations as a function of variable-ratio value.



## EXPERIMENT 8

This experiment investigated the effects of reinforcement omission on a VR 40 schedule. Both a light and a tone stimulus were presented in lieu of omitted reinforcements. Pause duration and running rate were analysed separately following either the preceding reinforcer on the preceding omission stimuli.

## METHOD

### Subjects

Rats 1, 2, 3 and 4 served. They had previous experience of VR schedules (see Experiment 7). They were housed and maintained as described in Experiment 7.

### Apparatus

The experimental chamber, scheduling and recording equipment was the same as used in Experiment 7. A tone stimulus with a frequency of 1000 Hz was produced by directing the output of a frequency generator through an amplifier to a 6-inch 15 ohm speaker located on the

lid of the experimental chamber. The intensity of the tone was 85 db. The light stimulus was produced by a 12 watt, 24 volts DC bulb located 6.0 cm above the centre of the lever.

### Procedure

The subjects were placed on a VR 40 schedule with each reinforcement accompanied by a 2-sec light/tone stimulus. The concentration of the milk reinforcer was held at 30% throughout the experiment; all sessions were terminated after 77 reinforcements. The subjects were exposed to the schedule for a minimum of 30 sessions after which the same stability criterion as used in Experiment 1 was in effect. When responding was stable, the subjects were exposed to a procedure in which 50% of the scheduled reinforcements were randomly omitted thus producing either reinforcement + light/tone stimuli or light/tone stimuli alone at the end of each completed ratio. The reinforcement omission procedure was in effect for four sessions after which the subjects were returned to the VR 40 schedule with 100% reinforcement.



## RESULTS

Figure 35 shows the mean durations of the pauses (See Table 14 for interquartile ranges) and the running rates following reinforcement and following the omission stimuli for the last four baseline sessions ( $B_1$ ), the four reinforcement omission sessions ( $O_m$ ), and the first four return-to-baseline sessions ( $B_2$ ). In all instances the duration of the pause following the omission stimuli was very much shorter than the duration of the post-reinforcement pause. There was a tendency, in three of the four subjects, for the duration of the post-reinforcement pause to decline during the reinforcement omission sessions relative to the baseline post-reinforcement pause; the exception to this was S1 where there was little difference between the baseline and reinforcement omission post-reinforcement pauses. For all the subjects there was a further decline in the duration of the post-reinforcement pause during the first four return-to-baseline sessions.

There was little difference between running rates following reinforcement and following the omission stimuli; the running rate following reinforcement was lower than the rate following the omission stimuli on three of the four omission sessions for Subject 1 and on two of the

Figure 35. The upper panels show the mean duration of the pause (solid lines) following reinforcement (closed circles) and following the omission stimuli (open circles). The lower panels show the running rates (broken lines) following reinforcement (closed circles) and following omission stimuli (open circles). Data are from each of the last 4 baseline sessions ( $B_1$ ), the four reinforcement omission sessions (Om) and the first four return-to-baseline sessions ( $B_2$ ).

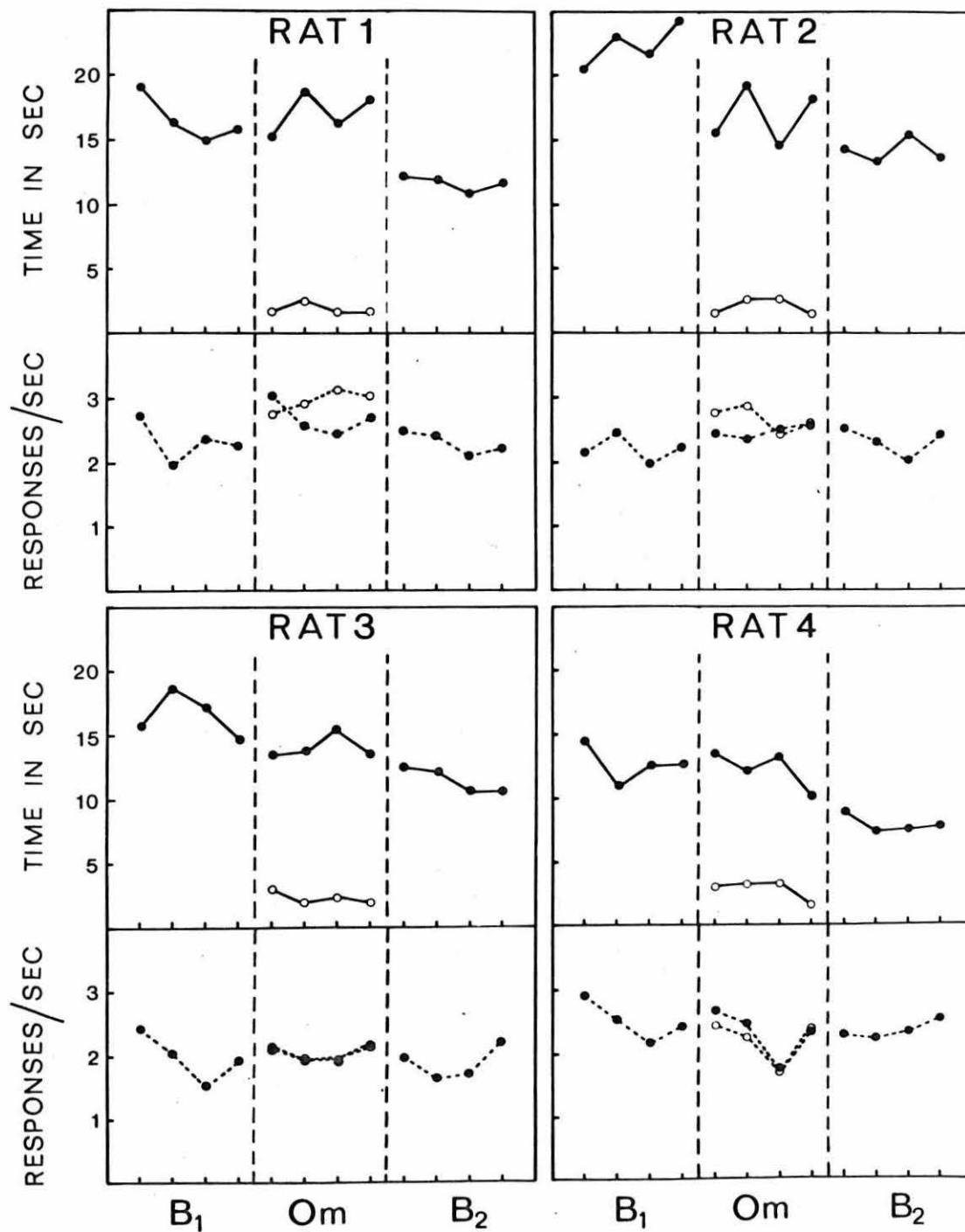


TABLE 14

The overall response rates and interquartile ranges of the durations of pauses following reinforcement in the baseline, reinforcement omission, and return-to-baseline sessions, and following omission of reinforcement in the test sessions.

ANIMAL	RESPONSE RATE (RESPONSES/SEC)				POST-REINFORCEMENT PAUSE (SECONDS)			
	BASELINE	OMISSION		RETURN-TO-BASELINE	BASELINE	OMISSION		RETURN-TO-BASELINE
		FOLLOWING:				FOLLOWING:		
		REINFORCEMENT	STIMULI			REINFORCEMENT	STIMULI	
1	1.17	1.21	2.58	1.42	13.9 - 17.1	15.8 - 19.0	0.7 - 2.1	11.5 - 14.3
2	0.94	1.19	2.30	1.28	16.0 - 20.3	14.6 - 18.4	0.9 - 3.2	12.9 - 15.8
3	1.05	1.12	1.81	1.24	13.2 - 17.5	13.0 - 15.5	0.8 - 2.9	10.3 - 13.0
4	1.35	1.37	1.87	1.61	10.1 - 13.5	11.0 - 13.6	0.9 - 3.3	7.5 - 9.6

omission sessions for Subject 2; for Subject 3 there was no difference over the four omission sessions and for Subject 4 the rate was initially higher following reinforcement than following the omission stimuli, but this difference was greatly reduced after the second omission session. For all the subjects there was little difference between the running rates on the baseline and on the return-to-baseline sessions.

Table <sup>14</sup> shows the mean overall rates for the baseline, omission and return-to-baseline sessions. In all instances, during the omission sessions, the overall rate was higher after the omission stimuli than after reinforcement. This was due, as is shown in Figure 35 to the reduction in pausing following the omission stimuli compared to the post-reinforcement pause, and not to any systematic change in running rates.

#### GENERAL DISCUSSION

The results of both experiments clearly show that the reinforcing stimulus has inhibitory after-effects on VR schedules.

In Experiment 7 it was shown that the duration of the post-reinforcement pause on VR schedules is directly related to the magnitude of the preceding reinforcer. This finding is consistent with the results of previous studies which have reported a similar relationship between post-reinforcement pause and magnitude of reinforcement on FI (Jensen and Fallon, 1973; Lowe et al., 1974; Staddon, 1970), and FR (Lowe et al., 1974) schedules. The absence of any systematic relationship between magnitude of reinforcement and running rate reported here is also in agreement with the findings reported by Lowe et al., for the FR schedule.

The results of Experiment 7 also show that the inhibitory after-effects of reinforcement magnitude are dependent upon the value of the VR schedule; the larger the VR value the greater is the inhibitory effect of any given magnitude of reinforcement. This suggests that the changes in the duration of the post-reinforcement pause consequent upon changes in reinforcement magnitude are not in any way absolute, but are relative to the baseline post-reinforcement pause produced by a particular schedule value.

In Experiment 8 it was shown that when some of the scheduled reinforcements are omitted from a VR schedule and a stimulus is presented in lieu of reinforcement, there is a marked reduction in the duration of the pause

following the stimulus relative to that following reinforcement. Although reinforcement omission has a considerable effect upon pause duration and overall response rate there is no systematic effect upon running rate. These results are in close agreement with findings from studies where reinforcement has been omitted on FI (Kello, 1972; Staddon and Innis, 1966; 1969) and on FR (McMillan, 1971) schedules, which have shown that the principal effect of reinforcement omission is a reduction in pause duration.

The findings of a direct relationship between VR schedule value and the duration of the post-reinforcement pause (Experiment 7) is in agreement with Farmer and Schoenfeld (1967), who found that on RR schedules post-reinforcement pause increased as schedule value increased. Farmer and Schoenfeld, however, also report that RR schedule value and running rate are unrelated which is contrary to the present finding of an inverse relationship between VR value and running rate. The reason for this discrepancy is not clear but may be related to the different way in which reinforcement probabilities are generated in VR and RR schedules.

The overall rate data, which show an increase in response rate as the VR value is increased are consistent with previous reports of overall response rate functions on RR schedules (Brandauer, 1958; Kelly, 1974). This function would appear to be inconsistent with formulations

of the Law of Effect which predict a direct rather than inverse relationship between rate of reinforcement and rate of response (Herrnstein, 1961; 1970). If, however, the post-reinforcement pause is excluded from the calculation of response rate and only the running rate is considered then there is a direct relationship between probability of reinforcement and probability of response. i.e., as VR schedule value increases, running rate decreases. Furthermore, the increasing overall rate function, which masks the decreasing running rate function, also masks an increase in post-reinforcement pause duration. However, though the absolute duration of the post-reinforcement pause increases with greater VR values, the proportion of inter-reinforcement time occupied by the post-reinforcement pause (see Figure 34) actually decreases, thus accounting for the positive relationship between schedule value and overall response rate. This adds further weight to the suggestion that schedule performance should be analysed not just in terms of overall response rate but also with regard to the running rate and to both the absolute and relative duration of the post-reinforcement pause (Lowe et al., 1974).

In summary, the results of the present experiments indicate that the reinforcer has inhibitory after-effects on VR schedules, and that these after-effects are in no way absolute but are relative to the parameters of the schedule.



## CONCLUSION

The results reported in this thesis show that on variable-interval and variable-ratio schedules the reinforcing stimulus comes to exert control over the temporal patterning of responses that follow its occurrence. In both the schedules this control was inhibitory, that is, the occurrence of a reinforcement was followed by a pause in responding. The duration of this pause was found to be dependent upon:

- (i) the magnitude of the preceding reinforcer,
- (ii) the presence or absence of the reinforcer
- (iii) in the VI schedules, the temporal distribution of reinforcements, and
- (iv) in the VR schedule, the mean ratio requirement.

In all instances the duration of the post-reinforcement pause was positively related to the magnitude of the preceding reinforcer, the extent of the effect being dependent upon the schedule in operation. Also, when some of the scheduled reinforcements were replaced by another 'neutral' stimulus, the duration of the pause following the stimulus was less than the duration of the post-reinforcement pause.

In the VI schedules the duration of the post-reinforcement pause, as well as being dependent upon the magnitude of the reinforcer, was a function of the temporal distribution of reinforcements. Although each of the schedules had the same mean inter-reinforcement interval, the distribution of the intervals around this mean value was different for each schedule. Thus, while the frequency of reinforcement was constant, the function relating the probability of reinforcement to the time that has elapsed since reinforcement was different. This variable, i.e., the manner in which the probability of reinforcement changed with the passage of time, affected both the duration of the post-reinforcement pause and the pattern of subsequent responding.

The effect observed upon the pattern of responding may be accounted for by assuming that in general the rate of responding at any one time is positively related to the probability of reinforcement obtaining at that time (cf.

Catania and Reynolds, 1968). The duration of the post-reinforcement pause is also affected by the differences in the function relating probability of reinforcement to the time elapsed since reinforcement, although the effect is indirect. The duration of the post-reinforcement pause is in part determined by the predictive properties of the reinforcing stimulus, that is, the extent to which the occasion of a reinforcement predicts the occurrence of subsequent reinforcement. This was demonstrated by the fact that on the arithmetic VI schedule, where there was a relatively low probability that two reinforcements will occur in close temporal proximity, the post-reinforcement pause was longer than it was on the constant probability VI schedule where the probability of reinforcement was constant irrespective of the time that had elapsed since reinforcement.

The present findings are consistent to a large extent with the hypothesis that the post-reinforcement pause is determined by a discriminative function acquired by the reinforcing stimulus (Staddon, 1972a). According to this, if reinforcement is frequently followed by a period of non-reinforcement, then the reinforcing stimulus functions as an  $S^\Delta$  setting the occasion for not responding, that is, the reinforcer acquires temporal inhibitory control over responding. The present data would seem to

support this to some extent since, on the schedules where the probability was low immediately following reinforcement, i.e., the arithmetic VI and the VR schedules, post-reinforcement pauses of appreciable duration were observed. Moreover, in these cases, the effect of the variations in the magnitude of reinforcement could be attributed to the reinforcer being a better or stronger stimulus when its magnitude was greater. Staddon's hypothesis cannot, however, adequately account for the fact that similar effects were also observed on the constant probability VI schedule and the arithmetic VI schedule with added short intervals. In these schedules the probability of reinforcement was either constant, irrespective of the time elapsed since reinforcement, or it was relatively high in the early periods following reinforcement because of the presence of added short intervals. In these situations Staddon's hypothesis would predict no particular controlling effect of the reinforcer upon the post-reinforcement pause. The effect however, was one of a positive relationship between the duration of the post-reinforcement pause and the magnitude of the reinforcer, it would appear, therefore, that the reinforcing stimulus had inhibitory effects, over and above any discriminative properties that it acquired.

Traditionally, several theories have attempted to explain the effects of the reinforcer in terms of its motivational properties (e.g., Amsel, 1962; Seward,

Pereboom, Butler and Jones, 1957). These accounts suggest that a drive state contributes to the vigour or speed of responding. For example, frustration, a primary drive-state, is hypothesised to be produced by the non-occurrence of reinforcement in the presence of stimuli anticipatory of that reinforcement. The motivation produced by this event, is considered to increase, for example, the running speed in the double-runway (cf. Amsel and Roussel, 1952). Similarly, the presentation of a large magnitude of reinforcement may be considered to demotivate the organism momentarily by reducing some physiological drive state and hence subsequent running speed (e.g., Seward et al., 1957).

The results of the experiments reported in this thesis do not support the motivational accounts of reinforcement. On the VI schedules the temporal distribution of the reinforcements was an important factor in determining the duration of the post-reinforcement pause, and the extent to which the duration changed as a function of the magnitude of the reinforcer. Also, on the VR schedule, as well as being dependent upon the magnitude of the reinforcer, the duration of the post-reinforcement pause was positively related to the mean ratio requirement specified by the schedule.

There is no evidence to suggest that any of the consummatory mechanisms postulated by Seward et al., (1957) can account for the fact that the reinforcer has a greater depressive effect on, for example, a VR 80 schedule than on an VR 10 schedule. Nonetheless, the duration of the post-reinforcement pause was greater on the VR 80 schedule than on the VR 10 schedule.

The effects of omitting reinforcements upon subsequent responding have often been interpreted in terms of the frustrative effects of non-reinforcement (Amsel, 1962). In the present experiments the principal effect of reinforcement omission was a reduction in the pause following a stimulus replacing the scheduled reinforcements, compared to the duration of the post-reinforcement pause. The effects upon response rate, on the other hand, were not as consistent. In the arithmetic VI and the VR schedules response rate following the omission of reinforcement did not differ systematically from the response rate following reinforcement. This is contrary to the effect predicted by the frustration theory. Moreover, the response rate following the omission of reinforcement on the constant probability VI schedule was lower than the response rate following reinforcement. That is, it was the direct opposite of the effect predicted by the frustration theory. Only in

the arithmetic VI schedule with added short intervals did the response rate increase following reinforcement omission. The present results are consistent with the hypothesis that the changes occurring following the omission of the reinforcer are due to the absence of the after-effects which normally accompany reinforcement, i.e., the generalisation decrement of the after-effects of reinforcement hypothesis (Staddon, 1970b).

In the VR schedule, as the ratio requirements was increased, thus reducing the overall density of reinforcement, the duration of the post-reinforcement pause also increased, reducing this density even further. Similarly, in the VI schedules the duration of the post-reinforcement pause was such that, to a greater or lesser extent, the maximum density of reinforcements obtainable by the organism was reduced. Moreover, on all these schedules, the duration of the post-reinforcement pause increased as a function of the magnitude of the reinforcer, causing a further deviation from the reward maximisation principle.

It has often been suggested that a guiding principle of an organisms behaviour is the maximisation of reinforcement. For example, Logan and Ferraro (1970)

state:

"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 towards optimal behaviour by the relative incentive value of the alternative behaviours. (p.119)".

While this principle may operate in a variety of situations, the present data show that this is not always the case.



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\* English spelling has been used throughout including the spelling of the word, e.g., behaviour, even when the reference is to an American article or journal.

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