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University of Wales.

TEMPORAL ORIENTATION

OF BEHAVIOUR.

Peter Harzem.

Ph.D. 1968.



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Peter Harzem.

CONTENTS

1
4
12
20
21
34
46
54
55
75
87

PART II.

CHAPTER 5. PROGRESSIVE INTERVAL SCHEDULES OF 99 REINFORCEMENT. 99 A. Introduction. 100 B. Apparatus 113 G. Method of deprivation. CHAPTER 6. ARITHMETIC PROGRESSIVE-INTERVAL SCHEDULES 114 OF REINFORCEMENT. Experiment 1 115 Arithmetic PI 15 sec. Experiment 2 Extended sessions on arithmetic PI 15 sec. 125 Experiment 3 131 Arithmetic PI 30 sec. Experiment 4 141 Arithmetic PI 60 sec and 90 sec 152 General discussion

CHAPTER 7. GEOMETRIC PROGRESSIVE-INTERVAL SCHEDULES OF REINFORCEMENT. 157 Experiment 5 Geometric PI 20% (60 sec). 158 Experiment 6 Geometric PI 10%, 20%, and 30% (60 sec). 168 Experiment 7 DRL performance after training on geometric PI schedules. 176 CHAPTER 8.

CONCLUSION: TEMPORAL ORIENTATION OF BEHAVIOUR. 181

REFERENCES

ABSTRACT.

Studies of performance on DRL and FI schedules of reinforcement have shown that organisms can adjust the distribution of their responses in time in accordance with the constant temporal characteristics of these schedules. In the present research an attempt was made to find out whether such adjustment also occurs when the temporal distribution of the presentation of reinforcements undergoes orderly change.

In Part I the relevant literature relating to performance on DRL and FI schedules is reviewed.

In Part II a series of experiments is described \ in which the behavioural effects of progressiveinterval (PI) schedules were investigated. In these schedules only the first response was reinforced in each of consecutively increasing timeintervals; the durations of the intervals increased by (i) arithmetic progression, or (ii) geometric progression. It was found that behaviour adjusted to the changing conditions of these schedules. The evidence was as follows:

1. The number of responses emitted in each interval of a schedule was relatively constant;

2. This number was less variable under geometric PI schedules than it was under arithmetic PI schedules;

3. The durations of the post-reinforcement pauses gradually increased in the course of the progression of a schedule;

4. The difference between the duration of an interval and the post-reinforcement pause in that interval became greater in the latter part of a schedule;

5. This difference was less under geometric PI than under arithmetic PI;

6. These relations were maintained in long sessions some of which lasted 12 hours;

7. There was some evidence that prior experience on PI schedules resulted in improved accuracy of performance on DRL.

It was suggested that the practice of referring to performance on temporally based schedules as <u>temporal discrimination</u> is inappropriate since discrimination implies the presence of a stimulus to be discriminated, whether external or internal. Performance on PI schedules could not be based on such stimuli unless a stimulus of different duration was postulated for every interval of the schedule. <u>Temporal orientation</u> of behaviour was proposed as an alternative term, reserving <u>temporal discrimination</u> for those situations in which the duration of an explicit stimulus is discriminated. CHAPTER 1.

INTRODUCTION:

HISTORICAL PERSPECTIVE.

Man's interest in time has a long history. For some two thousand years this interest in time formed part of a far bigger concern to understand the nature of the universe. With the rise of science in the seventeenth century, however, it became increasingly more important for dynamics and astronomy that time should be accurately <u>measured</u>. To this end Galileo, for example, invented several improved versions of clocks⁽¹⁾. A further approach to the study of time emerged in the latter half of the nineteenth century, under the influence of psychophysics; this was the

(1) Newton's concern with time was evident at an early age. At fourteen he built a clock made entirely of carved pieces of wood; it kept good time (Bell, 1937).

empirical study of the perception of time. The methods of Fechner and Weber were applied to measure the accuracy with which man could estimate time intervals, to discover the influence of the contents of intervals on awareness or "perception" of their durations, and so on.

Among the diverse views held about man and nature in general, there is one particular thesis with regard to time about which there is a surprising degree of unanimity, viz. that the notion of time is derived from the experience of change and succession. This view appears in different forms, but the underlying emphasis on change is common to all of them. Thus it is plain from the surviving fragments of his work that Heraclitus regarded the occurrence of change as a particular challenge. In Plato's Timaeus it is suggested that time, though the image of eternity, differs from eternity since it is moving. According to Aristotle time was a consequence of motion; "time", he said, "cannot exist without change" (Physics, book IV). Lucretius wrote "time exists not by itself, but from actual things comes a feeling, what was brought to a close in time past, then what is present now, and further what is going to be hereafter. And it must be avowed that no man feels time by itself apart from the motion, or quiet rest of things" (De Rerum Natura, bookI). Much later, St. Augustine conceived three kinds of time: "a present of things past, a present of things present, and a present of

things future" (Confessions, XI, xx). The first of these was memory and the last, expectation; it was the presence of all three which gave rise to the notion of time. But St. Augustine knew that his theory did not solve all of the problems associated with time. He wrote, "I confess to Thee, O Lord, that I am as yet ignorant of what time is" and "My soul yearns to know this most entangled enigma" (op. cit.).

Post-sixteenth century philosophers continued to consider change as the basis of time; they differed, however, about the nature of this change. Two main views appear to have been current. The first was that the concept of time arose from perception of change, the second, that it was the succession of ideas in the mind that formed the basis of time. There is an interesting example of the first view in Hume who wrote: "Whenever we have no successive perceptions, we have no notion of time", and "Time cannot make its appearance to the Mind, either alone, or attended with a steady, unchangeable object, but is always discovered by some perceivable succession of changeable objects" (A treatise on human nature, Vol I). In a different context we shall encounter again a problem touched upon by Hume; namely, what is the basis of temporal discrimination in the presence of no apparent change? The second view was held, for example, by Descartes who believed that time arose from inner experience as a consequence

of several different thoughts. Locke also held the view that time was based not on motion but on the succession of ideas: "whereever a man is, with all things at rest about him ... he will perceive the various ideas of his own thoughts in his own mind, appearing one after another and thereby find succession where he could observe no motion" (Essay concerning human understanding, Vol. I). Kant's view of time was similar but for a different reason: he was concerned with the importance of a common temporal basis for the laws of science. If time arose from the perception of change, then it was idiosyncpratic, dependent on individual experience. This could not be the case, however, and accordingly the notion of time was "acquired, being drawn not from some sensation of objects (for sensations provide the substance but not the form of human knowledge) but from the operations of the mind itself in accordance with the constant law governing the sensations of the mind" (Dissertation of 1772).

Fraisse (1964) has suggested that it was Kant who, by emphasising the activity of the mind as the origin of the notion of time, redirected subsequent approaches to the study of time. After Kant, philosophers, and then psychologists, became concerned more with man's awareness of time than with the origins of the concept of time. When psychology began to move into the laboratory in the latter part

of the nineteenth century there was already considerable interest in questions such as "how is time perceived?", "what constitutes the immediate experience of time?", and "what are the sensations which make up the perception of time?" Attempts to answer these and similar questions proceeded at two levels: by experiments and by methods of introspection (Boring, 1950).

The general pattern of the history of psychology is reflected in the subsequent course taken by the studies of time. The introspective approach of the Würzburg school gradually faded and lost its influence. The laboratory studies led to further refinement of the questions asked about the perception of time; these questions had to be rendered amenable to experimental analysis. Further, the progress of the experimental approach took two distinct directions. First , the experiments on the ability of humans to estimate time intervals continued. At the start these studies were concerned with the application of the new methods of psychophysics to the problems of time. As years passed the methods as well as instrumentation improved, and these studies continued until the present time (e.g. Gilliland, Hofeld and Eckstrand, 1946; Woodrow, 1951; Wallace and Rabin, 1960). It is interesting that the number of articles per year on human time estimation, quoted by the Psychological Abstracts, has varied little in the past Second **W**, as Pavlov's studies of forty years. conditioned reflexes and Watson's behaviourism began to influence psychology it became particularly

important to study the temporal relations between conditioned and unconditioned stimuli and responses. Moreover, the findings in Pavlov's laboratory on "temporal conditioning" (Zelenyi, 1907) attracted the attention of many researchers. Temporal conditioning consisted of the repeated presentations of conditioned and unconditioned stimuli together, at regular intervals⁽²⁾. When subsequently the stimuli were withheld, the conditioned response nevertheless continued with the same temporal This phenomenon was investigated in a regularity. variety of experimental situations with a variety of species, and remains an important area of current Soviet psychology (e.g. Dmitriev and Kochigina, 1959). The interest in Pavodvian temporal conditioning gave way to a new emphasis towards the end of the 1930's, due to two related factors. One of these was the development, by Skinner (1938), of the techniques of operant conditioning. This opened a vast area of research and enabled a reformulation of the traditional problems of psychology, including the problem of temporal orientation of behaviour, within The second factor was a a new conceptual system.

(2) Temporal conditioning can be established by presenting only an unconditioned stimulus at regular intervals, (e.g. Kimble, 1950). The method described above, however, was used in the early studies and remains the common method in the more recent Russian experiments (Dmitriev and Kochigina, 1959).

part of the first. Skinner emphasised the rate of responding as the important measure of behaviour and thereby directed attention to the temporal spacing of FIn his first major work Skinner operant responses. (1938) described an experiment which was explicitly concerned with temporal spacing of individual responses. It was not, however, until the early 1950's that workers in operant conditioning began to study in detail the distribution of responses in time. Since then, a considerable amount of precise information has become available on the subject. The present thesis is an attempt to extend further this body of knowledge on temporal orientation of behaviour. In Part I the basic problems are discussed and the relevant literature is reviewed. Investigations by the writer are reported in Part II, followed by consideration of the relation of the results to the available evidence.

PART I.

CHAPTER 2.

BASIC PROBLEMS.

Time, as a basic dimension of all events enters into any relationship which may beeobserved between two or more events. Such relations may, of course, be analysed along a variety of dimensions and the concomitant temporal relations may or may not be of interest in such analyses. In operant conditioning the fundamental relationship is temporal; that is, the relationship between response and the environmental event which is contingent upon that response. The apecial class of environmental events which are of central importance in operant conditioning are those called reinforcements. Moreover, a reinforcement contingency basically specifies a temporal sequencing

of responses and reinforcements. In the experimental analysis of behaviour the temporal relationship between a response and reinforcement is commonly held

constant; reinforcement follows immediately after the appropriate response, while other independent variables are manipulated. Numerous studies, however, have been concerned with the effect on behaviour of manipulating the temporal distance between response and reinforcement. In an early experiment by Skinner (1938), for example, reinforcement was delayed for intervals of 1 to 8 seconds and it was found that the rate of responding was inversely related to the duration of the delay. Similar results have been obtained under a variety of experimental conditions by several other investigators (e.g. Perkins, 1947; Grice, 1948; Keesey, 1964). Thus it is well documented that the immediate presentation of a reinforcer has a greater effect on the acquisition and maintenance of responding than delayed reinforcement.

Apart from the temporal nature of the basic relationship between response and reinforcement, a second way in which behaviour comes to be correlated with the temporal characteristics of the reinforcement is termed temporal discrimination. It is important to note, however, that a basic difference exists between temporal discrimination and other types of discrimination. The latter refers to a relationship between a stimulus and a response such that the stimulus "sets the occasion" for responding (Skinner, 1938). In the simplest case, for example, a response may be reinforced only in the presence of a stimulus and never in the presence of a different stimulus. An organism discriminates the two conditions by responding appropriately when the stimulus which signals the availability of reinforcement is presented. In temporal discrimination a similar pattern of behaviour occurs in the <u>absence</u> of discriminative stimuli: although the stimulus situation remains unaltered, responding correlates with the temporal restrictions imposed upon reinforcement.

An important consideration is that such correlations do not necessarily indicate the existence of temporal discrimination. An observed relationship between the pattern of responding and the temporal contingencies in operation may be due to other factors. In his discussion of temporal discrimination, Skinner (1938) illustrated this by pointing out that, for example, the emission of different response rates on fixed-interval 5 min and fixed-interval 6 min is the result of the relationship between the rate of responding and the frequency of reinforcement. Similarly, if two different responses are reinforced, one after a delay of two seconds and the other after eight seconds, the former would be emitted in preference. However this is attributable to the differential strengthening of the responses rather than temporal discrimination.

On the other hand, a temporal point in the course of a continuous stimulus may be distinguished by an organism if that point is reliably associated with some other event, in particular reinforcement. This, according to Skinner, is temporal discrimination. The formulation emphasises that in no way "does 'time' or 'an interval of time' enter with the status of a stimulus. Time appears as the single property of duration, comparable

with intensity, wavelength, and so on" (1938, p. 269).

Of course, discrimination of intensity is discrimination of a stimulus in terms of its intensity. But what of temporal discrimination which occurs in the absence of stimulus change? There is no difficulty when the duration of an explicit stimulus is discriminated (e.g. Reynolds and Catania, 1962) because this fits exactly the above formulation. However a different (and more commonly studied) type of temporal discrimination is one in which the onset of the interval to be discriminated is signalled by a brief event. Usually this event is a response or a reinforcement, so that the onset of the interval is controlled by the subject (Skinner, 1938). This need not always be the case since a brief signal could be presented independently of behaviour and the next response reinforced only if it occurred after a given interval (e.g. Zimmerman, One basic characteristic of this type of 1961). arrangement is that the prevailing stimulus situation is identical before and after the signal. Assuming that temporal discrimination of the required interval after the signal does develop, what is being discriminated in terms of its duration? It is this kind of consideration which has led some writers to appeal, by analogy, to internal stimuli (e.g. Anger, 1963). The suggestion is that the event signalling the onset of the interval to be discriminated also initiates some change within the organism, and that this change serves as a stimulus which is then discriminated in terms of its duration.

Recently Morse (1966) strongly argued that "our understanding of schedule performances is fettered by the tendency of many authors to explain schedule performances as discriminations of subtle differences in inferred stimulus conditions. Explanations of schedule-controlled patterns of responding in terms of temporal discriminations neglect the multiple sources of control of schedule performances" (p. 86). It is well documented, however, that timecorrelated cyclical processes do take place within organisms (e.g. Webb and Brown, 1950; Cold Spring Harbor Symposia on Quantitative Biology; Biological Clocks, 1960; Symposium: Rhythmic Functions in the Living System, 1962; Rohles, 1966, pp. 694-695) and it seems reasonable to assume that temporal discrimination is in some way related to such internal processes (cf Brady and Conrad, 1960). Difficulties arise when this assumption is extended by attributing hypothetical characteristics to unobserved internal stimulus events. Hurwitz (1967) recently wrote " But these stimuli are entirely response inferred and cannot be manipulated; a direct test of Anger's analysis (appealing to such stimuli) does not therefore seem possible. On the other hand, a closer examination of the behaviour may shed light on the basic problem" (p. 551).

Most of the literature which will be selectively reviewed in the following chapters is, in fact, directed at detailed analysis of behaviour which correlates with the temporal distribution of reinforcement. These studies are primarily concerned with basic questions of the following kind: (i) can organisms discriminate time intervals? (ii) if so, under what conditions is this type of behaviour acquired and maintained? (iii) what are its limits? In the course of such considerations the problem of what are the stimuli involved in temporal discrimination arises repeatedly; it arises in particular, in studies of the role of collateral behaviour in performance on differential reinforcement of low rates, and of mediating behaviour in performance of fixed-interval schedule of reinforcement.

In this Part recent experiments which investigate the behavioural effects of two types of schedules of positive reinforcement are discussed; namely, differential reinforcement of low rates (DRL) and fixedinterval (FI) schedules. It is the performance under these two schedules which is generally considered to provide the main body of evidence on temporal discrimination. Another major area of operant research in which temporal discrimination plays a part, free-operant (Sidman) avoidance (Anger, 1963; Sidman, 1966) has not been included. In his review of the relevant literature Sidman (1966) stated that "the small magnitude of (temporal) discrimination, its relative imprecision, and the small proportion of the animal's responses involved in the discrimination, all suggest that temporal processes are secondary in the acquisition of avoidance behaviour" (p. 464). In his first major work, Skinner (1938) pointed out that whenever regular temporal relations exist between events, whether explicitly

programmed or not, temporal discrimination will sooner or later develop. Thus, temporal discrimination may not be a necessary component of performance on free-operant avoidance but it may develop with prolonged exposure to the schedule. Moreover, the present thesis is primarily concerned with correlations between the temporal distributions of responses and of positive reinforcements. It is important to note here, however, that temporal discrimination in avoidance situations may be discrimination of durations of explicit events, that is, durations of lever presses. The remark by Hurwitz (1967) which was quoted above was with reference to an investigation of lever holding behaviour in free-operant avoidance. Hurwitz also commented that "on the basis of this analysis one could still describe the effect as involving 'temporal discrimination'. Anger's (1963) suggestion that such discrimination is based on responseproduced stimuli would assume new meaning since the response which serves to provide the stimulus source is not the press but the hold. (This) suggests the hypothesis that reinforcement of holding forms the basis of the temporal discrimination" (1967, p. 554). It turns out, then, that temporal discrimination in such situations may conform fully with Skinner's (1938) definition of time as a property of a stimulus, discriminated in terms of that property.

One proposal of the present thesis is that the term'temporal discrimination' should be reserved for those situations in which what is discriminated is the duration of an explicit event, whether it is a stimulus or a response. The temporal distribution of responding which correlates with the specification of the distribution of reinforcements in time is best described as <u>temporal orientation</u> of behaviour. In the next two chapters the term 'temporal discrimination' is nevertheless retained since it is used consistently in all the studies to be discussed. In Part II, however, investigations by the writer, of behaviour under Progressive Interval (PI) schedules will be reported and further evidence will be presented in support of the distinction suggested above.

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CHAPTER 3.

DIFFERENTIAL REINFORCEMENT OF

LOW RATES.

Differential reinforcement of low rates (DRL) was first used in an experiment by Skinner (1938), not as a separate schedule of reinforcement but superimposed upon a FI schedule, in order to demonstrate that the rate of responding at the moment of reinforcement is an important variable in determining the overall response rate. Since early 1950's DRL has been employed as a distinct schedule of reinforcement, especially in studies of temporal discrimination.

Under DRL a response is reinforced only if a specified minimum interval has elapsed since the preceding response. If a response is preceded by an inter-response time (IRT) shorter than the specified interval no reinforcement occurs and timing starts again from that response. In DRL all IRT's which exceed the required minimum are reinforced. However, a further restriction may be imposed by the addition of a limited hold (LH) specification which sets an upper limit to the IRT's which will be followed by reinforcement. Thus in DRL 20 sec, for example, all responses which occur after IRT's longer than 20 sec are reinforced; in DRL 20 sec LH5 sec, on the other hand, reinforcement occurs only if an IRT is longer than 20 sec and shorter than 25 sec.

A. PATTERN OF BEHAVIOUR.

Organisms are in fact able to distribute their responses in time so that a correlation emerges between the rate and temporal patterning of responding and the requirements of a DRL schedule. In this section the evidence relating to the basic characteristics of DRL performance are discussed.

1. Rate of responding.

Skinner (1938, pp. 306-307) briefly described the experiment mentioned above, in which rats were trained to respond at a high rate first on a fixedratio (FR) and then on a fixed-interval (FI) schedule of reinforcement. A DRL 15 sec schedule was then superimposed upon the FI so that a response was reinforced only if it met the criteria of both the FI and the DRL. The rates of responding gradually declined and became stable at a low level. Reinstatement of the FR schedule resulted in abrupt recovery of the previously observed high rates.

Subsequent research has shown that the rate of responding on a DRL schedule is inversely related to the duration of the minimum IRT required for reinforcement in that schedule (Wilson and Keller, 1953). Further, the specific control of rate by a given DRL can be demonstrated in the following way: if two different DRL schedules are alternated, each in the presence of a discriminative stimulus, a different response rate occurs under each schedule. Zimmerman and Schuster (1962) employed such a multiple (mult) schedule with two DRL components and a time-out period (TO) during which no reinforcement was available (mult DRL 36 sec TO intervened between the two DRL 18 sec TO 3 min). DRL's at every alternation and a continuous tone was present during DRL 36 sec. In each complete cycle of the multiple schedule DRL 36 sec was in effect for 16 min and DRL 18 sec for 8 min. The rats developed two different, stable rates of responding under the two DRL schedules. Approximately equal numbers of reinforcements were obtained in the two components, and this matched the equal reinforcement opportunity provided by the experimental conditions.

The control of rate by DRL is also seen when this schedule alternates with one which generates a high response rate. In an investigation by Ross, Hodos and Brady, (1962) monkeys responded under a multiple schedule with free-operant (Sidman) avoidance and DRL components, TO separating the alternations as in the above experiment. Efficient stable behaviour developed so that a very high rate of responding occurred in avoidance and the animals rarely received a shock. In DRL the rate was low and steady; the efficiency of temporal discrimination was such that in every 15 minute period of DRL 25-30 reinforcements were obtained, and "during the several months of this study the animals received no food other than that which they acquired during DRL periods" (p. 469). Long (1962) has demonstrated that responding of pre-school children could be similarly controlled by a mult DRL FR schedule.

Figure 1 shows a cumulative record obtained in an experiment by the present writer, as an example of responding on DRL. In that experiment human subjects responded on a tandem schedule which had six components, one or two of which were DRL. The record also shows the abrupt increase in the rate of responding when the next, FR 20, component came into operation.

When a DRL contingency is superimposed upon another schedule, as in Skinner's original experiment, the rate of responding declines. Ferster and Skinner (1958) found that with FI schedules the decline is roughly proportional to the minimum IRT requirement of the DRL. In a detailed study of this phenomenon Farmer and Schoenfeld (1964) superimposed DRL 1, 2, 4, 8, 16, and 24 sec, in successive blocks of 20 daily sessions (40 for DRL 24 sec) and in that order, upon baseline performance on FI 30 sec. Reinforcement occurred only if a response met the criteria of both FI and DRL. The response rates of rats declined as an inverse function of the minimum IRT specified by the

Figure 1 Sample cumulative records of human performance on DRL schedules. The two upper segments of the inset show responding on DRL 10 sec and the lower segment responding at first exposure to DRL 30 sec. The larger of the lower two records shows transition, at the first arrow, from responding on FR 40 to DRL 10 sec. After the last closely spaced reinforcement in segment A the schedule was changed to DRL 30 sec and at the second arrow, to FR 20. The bottom record is another example of responding on DRL 10 sec.



DRL schedule in operation. However the characteristic pattern of responding under the FI schedule was preserved. Even the shorter DRL values of 1, 2, and 4 sec were effectively related to the rate of responding, even though these represented only a small proportion of the FI 30 sec which limits the frequency of reinforcement.

2. Inter-response times.

The rate measure is, of course, a statement of the average number of responses which occur per unit time. and it is therefore perfectly correlated with the average IRT. Since studies of temporal discrimination are concerned with the distribution of responses in time, such averaging may overlook details which, from the present point of view, are of particular importance. The difficulty may be overcome by recording individual IRT's and summarising the results in relative frequency distributions (Sidman, 1956) or in distributions of conditional probabilities. Anger (1956) has argued in favour of the latter type of analysis and has introduced the "IRT's per opportunity" measure which is based on the consideration that in a given interval the opportunity for the occurrence of short IRT's is greater than for long IRT's. This measure involves first the calculation of the percentage of total time left for the emission of other IRT's, given that IRT's of, for example, the shortest recorded duration occupy

a proportion of the total session. Then, the total time left after the shortest and the next IRT classes is calculated and so on. The next step is to calculate the proportion of the time occupied by an IRT class in the percentage of total time left after the preceding IRT classes have been taken into account; this is the "IRT/opp" measure. The method is illustrated in Figure 2 (Sidman, 1966).

In fact, analysis of IRT's, in addition to providing more detail, may reveal temporal discrimination which is not always reflected in measures of response rate. For example, in a study of the effect of condition**gu** fear on timing behaviour, Migler and Brady (1964) found that the presentation of a warning stimulus which is terminated by an unavoidable shock suppresses the response rate but it does not alter the temporal distribution of the responses which are emitted.

Typically, the frequency distributions of IRT's are bimodal (Figure 3). One mode occurs at the shortest recorded interval (approximately 0-2 sec) and the second mode at or just below the minimum reinforced IRT class (e.g. Sidman, 1955; Conrad, Sidman and Herrnstein, 1958; Holz, Azrin and Ulrich, 1963). The latter mode signifies that the temporal distribution of a large proportion of responses matches the requirements of the DRL schedule in operation. IRT classes on either side of this mode gradually decline in relative frequency, so that the



Figure 2 Three methods of depicting the probability of interresponse times are shown (the data were from a free-operant avoidance experiment). The histogram shows the number of IRT's in each class, divided by the total number (N) of IRT's during the session; the dotted curve shows the percentage of the total IRT's that was greater than the lower limit of each IRT class (t); the dashed curve shows the number of IRT's in each class, divided by the total number of opportunities (OPP) for IRT's in that class (Reproduced, with permission, from Sidman, 1966).



Figure 3 A typical relative frequency distribution of IRT's for the rat. Data were obtained from a single animal, under DRL 20 sec.
distribution resembles a generalisation gradient. Sidman (1956) has pointed out that the gradient of the frequencies below the minimum reinforced IRT class may reflect a generalisation effect. However, the larger IRTs are under different control since they are always reinforced. The decline in the frequency of these may be due to the fact that they reduce the overall frequency of reinforcement (cf Ferraro, Schoenfeld and Snapper, 1964).

The relatively high frequency of very short IRT's reflects the occurence of response bursts. The reasons for the persistence of these response bursts is poorly understood; they occur not at random but with a high probability after an IRT which is just short of the minimum required for reinforcement (Sidman, 1956). This has led some writers to suggest that the response bursts are in some way related to the "timing process" (Conrad, Sidman and Herrnstein, Recently, Ferraro, Schoenfeld and Snapper (1965) 1958). presented evidence, one part of which has a bearing on this suggestion. They found that the probability of an IRT which meets the DRL criterion is higher after very short IRT's than after longer but still unreinforced IRT's. It seems that an interval initiated by a burst of responses may be better discriminated; and this may explain the maintenance of response bursts in DRL performance.

Although most of the published studies report relatively high frequency of the shortest recorded IRT class, this finding is not uniform. In a detailed study Kelleher, Fry and Cook (1959) investigated the behaviour of rats under several DRL schedules with LH. They found no bursts of responding; in general the probability of a response remained very low during the first ³/₄ of the minimum interval required for reinforcement and then increased sharply to a peak in the region of the reinforced IRT. The LH contingency tends in general to sharpen the IRT distribution. Also, Kelleher et al used a loud 'click' which occurred However, to check whether this at each response. accounts for the difference of their results from most others, they ran a further experiment with different rats without the LH or the click. Again no bursts The writers suggest that other were observed. differences in their experiment such as deprivation conditions, reinforcers, or apparatus may have contributed to the difference of their results. It seems that while bursts of responses do commonly occur in DRL performance, accurate temporal distribution of responses can also be observed in the absence of such bursts. Evidence relating to the possible function of these bursts in temporally spaced responding was mentioned above. Related to this are the findings that certain operations such as punishment (Holz, Azrin and Ulrich, 1963) and extended exposure to different DRL's (Staddon, 1965) selectively reduce the frequency of these bursts.

3. Sequential characteristics.

Several investigators have noted that in performance under a DRL schedule reinforcements tend to occur in relatively long sequences (Kelleher, Fry and Cook, 1959; Mallott and Cumming, 1964); and that the probability of a sequence of two reinforced responses is greater than the probability of a sequence of two responses of which only the second is reinforced (Farmer and Schoenfeld, 1964). Two studies in the literature report detailed analyses of these apparent serial dependencies. In one, Ferraro, Schoenfeld and Snapper (1965) investigated the sequential properties of behaviour under DRL 60 sec. With rats as subjects, about 140 consecutive daily conditioning sessions were run, followed by five extinction and one reconditioningssessions. Overall results of the final two conditioning days showed a high level of accuracy in the temporal distribution of responses: slightly better than 2 out of every 3 responses were reinforced; long runs of successive reinforcements occurred, interrupted by either a long pause or a burst of responses. A trend was observed toward longer IRT's as a session progressed. First order sequential analysis of IRT's revealed a positive correlation; that is, there was a high probability that an IRT would be followed by an IRT The difference between two of similar duration. successive IRT's was very small when the duration of the preceding IRT was in the region of 60 sec (the

31

minimum reinforced IRT) and somewhat larger when the preceding IRT was farther from that region. These results are summarised in Figure 4, reproduced from Ferraro, Schoenfeld and Snapper (1965, p. 258). The relationship shown in this Figure involves a relatively high frequency of reinforcement, especially if IRT's longer than 60 sec tend to be followed by IRT's which are shorter but still longer than 60 sec; and if IRT's shorter than 60 sec are frequently follwed by longer IRT's. Inspection of the sequential dependency functions shown in Figure 4 reveals that this was the case for two of the three subjects. For all subjects the effect was most marked in the case of very short IRT's (0-6 sec); these tended to be followed by IRT's around 60 sec.

An even more detailed analysis of serial interactions in DRL performance, carried out by the use of a digital computer, was reported by Weiss, Laties, Siegel and Goldstein (1966). These investigators used monkeys as subjects, responding on DRL 20 sec. No preliminary training was given. Yet the subjects began to respond almost immediately and sequential interactions were observable as early as the first session. Efficient responding developed rapidly, and by about the 8th session 50% of responses were reinforced. At that time more marked sequential effects were evident: "the IRT's drifted up and down in extended trains of reinforced and unreinforced responses" (p. 621). In further sessions remarkably stable responding occurred; in one session for example



Figure 4 Mean IRT's during the last two sessions as a function of the mean of the preceding IRT's during these sessions. On each abscissa the last category contains all cases where the preceding IRT values were greater than 132 seconds (Reproduced with permission from Ferraro, Schoenfeld and Snapper, 1965).

233 of the first 256 responses of one subject were reinforced. The records of this performance were subjected to detailed analyses by two techniques: autocorrelation analysis and spectral analysis. The techniques are described in detail by the authors (pp.. 622-624); the results indicated the existence of subtle sequential interactions. First order dependencies were also evident in diminished amplitude. The pattern of responding was in the form of a slow wave-like drift in which IRT's, some just short of the DRL criterion and some above it, alternated in The authors suggest that the subtle effects sequences. revealed in this experiment may be based on overt chains of behaviour which are thought to mediate temporally spaced responses: these chains would drift since they are adventitiously reinforced.

The evidence relating to the role of collateral behaviour in temporal discrimination will be discussed later. As Weiss et al point out, the important point here is that detailed analysis of sequential interactions reveal subtle characteristics of temporal discrimination.

B. EXPERIMENTAL MANIPULATIONS.

In this section we shall be considering what happens to DRL performance when certain independent variables are systematically manipulated. In general the rate of responding and the temporal distribution of responses are differentially affected by experimental changes. It appears that once established, temporal discrimination is less susceptible to these changes. When IRT distributions are nevertheless affected, longer IRT's within the distribution still occur with a relatively high frequency; when responding recovers after complete cessation, it recovers rapidly with little or no change in its temporal characteristics.

1. Deprivation and Satiation.

The positive correlation within limits, between deprivation level and the rate of responding is also observed in DRL performance. Conrad, Sidman and Herrnstein (1958) found that the response rate of a rat on DRL 20 sec increased sharply at low levels of water deprivation between 9 and 21.5 hours. Beyond this, between 21.5 and 65.5 hours of deprivation, the increase in rate was very gradual. Once a week the subject was tested at different durations of deprivation in mixed order, and stable responding was maintained in the remaining daily sessions on 21.5 hours of deprivation. A monkey was similarly trained but without access to food or water during deptivation and was tested at different periods. The results were similar; the rate of responding rose sharply at 0-7 hours of deptivation and more gradually beyond this, up to 72 hours. There was little change, however, in the IRT distributions of both animals. The most noticeable effect was observed on long IRT's exceeding

30 seconds. The percentage of these declined sharply with increases at low durations of deprivation and slightly at longer deprivations. The percentage of IRT's shorter than 10 seconds showed very little change.

Similar results were obtained by Mechner and Guevrekian (1962) with water-deprived rats. These investigators used a modified DRL procedure which enabled a distinction to be made between the post-reinforcement pause and the temporal discrimination pause. The procedure required a chain of two different lever responses for reinforcement, with a DRL 5 sec contingency between the two responses. A response on the second lever was reinforced if the DRL criterion was met; if not, a response on the first lever re-started the cycle. The mean duration of the pauses between the two responses was around 5 seconds and remained unaffected by deprivation periods of 8, 16, 24, 32, 40, and 56 hours. There was no change in the variability of these pauses. The inverse relation observed by Conrad et al between the long IRT's and the deprivation period at low levels was also observed in this experiment, but the effect was on the durations of post-reinforcement pauses and not on timing. With increases in the duration of deprivation up to the middle ranges the animals paused less after reinforcement; beyond the middle range there was little difference. The accuracy of timing the minimum required interval between the two responses, however remained remarkably stable.

In the study by Conrad, Sidman and Herrnstein (1958) the effects of progressive satiation on DRL performance was also investigated. The schedule was DRL 20 sec for two rats, DRL 20 sec LH 4 sec for one rat, and DRL 20 sec LH 2 sec for another rat. A satiation session lasted 10 hours. The results were similar to those obtained with different levels of deprivation; that is, the rates of responding declined as satiation progressed. There was little change in IRT distributions, however, except at extreme satiation when long IRT's became more frequent.

An inverse relationship between the rate of responding and the deprivation weight is also observed in the pigeon, whether the weight is manipulated by deprivation or by deprivation and satiation (Holz and Azrin, 1963; Reynolds, 1964). However, the selective effect is not observed in this bird and IRT distributions change as well as the rate. Reynolds found (1964) that a decline in the response rate was related to a selective decline in the relative frequencies of There appeared to be an improvement in short IRT's. the temporal distribution of responses with satiation and low levels of deprivation. However, the pigeon performs poorly under DRL schedules (Reynolds and Catania, 1961; Holz and Azrin, 1963) and it is doubtful whether the change can be attributed to improved temporal discrimination.

2. Aversive stimulation.

When a punishment contingency is added to all responses maintained under a schedule of positive reinforcement the rate of responding declines as a function of the intensity of the punishing stimulus (Azrin and Holz, 1966). This effect is also seen in DRL performance with accompanying changes in the relative frequencies of IRT's. Holz, Azrin and Ulrich (1963) first trained pigeons to respond on DRL 30 sec and then superimposed a shock contingency on each response. An ascending series of shock intensities from 30V to 120V were used in successive blocks of daily sessions. As the shock intensity increased the rate of responding declined, with concomitant increases in the number of reinforcements obtained in a session. The increase in the overall rate of reinforcement reflected the change which occurred in the IRT distributions. Punishment produced a marked reduction in the relative frequency of very short IRT's, and the median IRT successively shifted to longer durations with increases in punishment intensity. These findings were confirmed in a further study by Holz and Azrin (1963).

Other aversive events also result in suppression of DRL performance. Leaf and Muller (1964) found that a conditioned emotional response (CER) procedure completely suppressed the responding of rats during the conditioned stimulus. Migler and Brady (1964)

38

studied the effects of a similar procedure specifically on timing behaviour. They trained rats on a modified DRL schedule, similar to that used by Mechner and Guevrekian (1962). Two successive nosepresses on each of two keys were followed by reinforcement provided that the interval between the two responses exceeded a specified minimum duration. The final phase of the experiment is of interest The following conditions were in effect, here. in this phase: the minimum required interval between the two responses was 5 seconds and reinforcement occurred according to a variable-ratio (VR) 2 A clicking sound which lasted 5 minutes schedule. alternated with 5 minutes of no sound throughout a session. Each presentation of the sound was terminated by a brief electric shock. Daily sessions lasted 7.5 hours and no additional food apart from pellet reinforcers, was provided in the course of the entire experiment. The rate of responding declined each time the sound was presented: the number of responses emitted during the sound was approximately one quarter of the number of responses during no sound. Under both conditions, however, good temporal discrimination was maintained; the mean of the intervals between the two different responses was slightly above 5 seconds. There was little variability around the mean for two animals and slightly greater variability for one animal.

39

3. Extinction and reconditioning.

The change in behaviour which occurs in extinction resembles the effects of manipulating the motivational variables discussed above. In their study Kelleher, Fry and Cook (1959) also reported the results obtained in single two-hour long extinction sessions with the rats which had been trained on DRL 20 sec LH 5 sec. They found that responding continued throughout the session at a declining rate with little change in the IRT distributions apart from a slight increase in the frequency of IRT's between 9 and 15 sec and a slight decrease in longer IRT's. The IRT's which met the criterion of the schedule continued to occur in sequences. The final phase of the study by Ferraro, Schoenfeld and Snapper (1965) consisted of five extinction sessions followed by one reconditioning session. Responding declined sharply in extinction; as few as a total of 50-60 responses being emitted in the 5 extinction sessions. When the responses did occur, however, they occurred in sequences with IRT's appropriate to the DRL 60 sec schedule under which the rats had been trained (cf Hurwitz, 1957).

The difference of the pigeon's DRL performance is also observed in extinction. Reynolds (1964) found that extinction, after training on DRL 20 sec, changed both the overall rate and the IRT distribution. The conditional probability of short IRT's declined more rapidly than that of long IRT's, resulting in a more appropriate spacing of responses with respect to the DRL schedule. However the results obtained by Holz and Azrin (1963) are not in complete agreement. In their study, the frequency of short IRT's remained unchanged for two pigeons and increased for one pigeon. However, the IRT distribution became more uniform in the latter stages of extinction, due to a gradual increase in the frequency of long IRT's. The rate of responding declined slowly in the first two sessions, then more sharply in the next two, and again slowly after that.

Reinstatement of the DRL schedule after extinction results in very rapid recovery of performance. Ferraro, Schoenfeld and Snapper (1964) found that, although reconditioning of rats was rapid, temporal discrimination was not as accurate as in the final conditioning session. Reynolds (1964a) reported that the response rate and the IRT distributions of pigeons recovered after as few as two reinforcements in reconditioning. He suggested "that the process in this instance is related to performance rather than to relearning. From the two reinforcements, the bird does not relearn the temporal spacing of successive pecks that prevailed before extinction any more than it relearns to peck" (pp. 274-275). However, the behaviour which recovered was one of high rate and very few reinforcements; the distribution of responses in the final extinction session was such that 10 reinforcements would have occurred in about 15 minutes. This behaviour continued in the first

3 minutes of the reconditioning session and the two reinforcements were obtained. This was followed by a sharp return of the rate of responding to its pre-extinction level with the consequence that no reinforcement occurred in the next hour.

4. Rate of reinforcement.

Performance under a variety of schedules of reinforcement is related to the overall frequency of reinforcement as well as the effect of reinforcement at the time it occurs. For example a proportional relationship exists between the rate of reinforcement and the rate of responding on interval schedules (Skinner, 1938; Herrnstein, 1961). In DRL performance the gradual decline in the relative frequency of IRT's above the minimum reinforced IRT has been thought to be due to the fact that long IRT's reduce the overall frequency of reinforcement (Anger, 1956; Conrad, Sidman and Herrnstein, 1958). For this reason analysis of the effect of reinforcement frequency on DRL performance is of particular interest. The rate of reinforcement is, of course, commonly controlled by the behaviour of the subject; a schedule imposes limits on that rate. However, Zimmerman (1961) has reported a study in which the rate of reinforcement was controlled as an independent variable. This study used a modified discrete trial DRL procedure. Each interval to be timed was

signalled by a discriminative stimulus (S^D): if a specified interval elapsed before the next response reinforcement occurred and S^D was terminated. A response after a shorter interval resulted only in the termination of S^{D} . Responses during the S^{Δ} periods (i.e. when S^D was not present) were ineffective. A LH contingency was also in operation so that if a response was not emitted within a given interval after reinforcement became available S^ occurred. Three schedules were used: DRL 18 sec LH 12 sec. DRL 6 sec LH 24 sec, and DRL 6 sec LH 2 sec, each under two different conditions. In the recycling schedule a fixed 6 second period of S^{Δ} followed the termination of the LH period, as weld as all of the responses which occurred in the presence of S^D whether reinforced or not. Thus, the overall rate of reinforcement was controlled by the subject within the limits of the schedule in operation. In the fixedtrial[S^A occurred as described above but its duration depended on the duration of the interval between the onset of S^D and the next responses. The time between S^{D} onsets and therefore the number of occasions in which reinforcement could occur was held constant.

Analysis of S^D-R intervals showed very low relative frequencies below the minimum reinforced interval and a sharp mode just above it. The distributions of re-cycling and fixed-trial schedules differed under DRL 18 sec LH 12 sec and DRL 6 sec LH 24 sec but a more marked difference was observed under the latter schedule. In fixed-trial schedules the distributions were less peaked and the frequencies above the minimum reinforced interval declined more gradually, reaching zero in the final part of the LH period.

DRL 6 sec LH 2 mimimised the difference between the two schedules since LH was very short. As a result no difference was observed between the relative frequency distributions.

The evidence indicates that the overall rate of reinforcement is an important variable in the control of temporally spaced responding. However, relatively sharp peaks just above the minimum reinforced interval were also observed in the fixed-trial schedule. As Zimmerman points out, "some factor or factors beside the rate of reinforcement must account for the subjects' great tendency to respond shortly after a reinforcement is set up" (1961, p. 224).

5. Drugs.

A great deal of evidence has shown the importance of the application of operant conditioning techniques in the analysis of the effects of drugs on behaviour (Boren, 1966). DRL schedules are particularly useful in the study of the effects of some drugs such as the amphetamines signee their effects are best revealed on responses which occur at a low rate (Sidman, 1955). Since some of these studies provide further evidence related to the distribution of responses in time, it is appropriate to consider them here.

Dews and Morse (1958) studied the effect of dextro amphetamine on human performance on two DRL schedules with FR requirement. On one schedule every 10th

response which met the criterion of DRL 25 sec was reinforced; on the second, FR 100 and DRL 2.5sec were in effect. The IRT distributions were similar under the two schedules, with a peak just above the minimum reinforced IRT and declining frequencies of IRT's above that. Administration of dextro amphetamine (5 mgm) resulted in a shift of the IRT distributions in the direction of the shorter IRT's. Schuster and Zimmerman (1961) found a similar but considerably more marked effect on the performance of rats under DRL 17.5 sec. They prolonged the administration of dl-amphetamine (0.75 or 1.5 mgm/Kg) in alternate daily sessions and on other days recorded the activity level of the The chronic treatment with the drug resulted animals. in gradual return to longer IRT's but the activity which was initially increased by the drug showed no decline. In a later study, more fully discussed above, Zimmerman and Schuster (1962) found that chronic administration of d1-amphetamine (1.0 mgm/Kg) differentially disrupted performance on a multiple DRL schedule. The frequency of short IRT's increased in both components and then gradually declined. The initial effect was more pronounced on DRL 38 sec than it was on DRL 18 sec. This initial difference was maintained throughout the subsequent shifts observed in the IRT distributions of the two DRL schedules. Segal (1962) also reported similar results. He administered d1-amphetamine (0.5 to 2.5 mgm/Kg) to

rats under DRL and concurrent VI DRL schedules of reinforcement. The effect was a shift of the IRT distributions towards the shorter IRT's but the temporal distribution of responses was not lost. Segal concluded: "the main effect of the drug was apparently a motor-excitatory one, and not a specific disruption of some <u>internal</u> timing mechanims" (p. 111).

C. COLLATERAL BEHAVIOUR.

Segal's reference to an internal timing mechanims again raises the question of what enables organisms to space their responses in time with considerable accuracy. One suggestion is as follows. Any behaviour which precedes a response is also reinforced when that response is reinforced. In DRL schedules a response is reinforced only if a given interval has elapsed since the previous response and thus the behaviour preceding the reinforced response occupies an interval which meets the criterion. This collateral (or "mediating": cf Ferster and Skinner, 1957) behaviour is gradually, and 'superstitiously', strengthened so that it regularly intervenes between responses. As a result responses are spaced in time with considerable accuracy.

The occurrence of fairly stereotyped collateral behaviour in DRL performance was first observed by Wilson and Keller (1953). Since then the phenomenon

has been well documented. Bruner and Revusky (1961) reported a study in which collateral responses were recorded and analysed. They reinforced the key pressing responses of schoolboys on DRL 8.2 sec Three irrelevant keys were also LH 2.05 sec. provided; responses on these were without consequence but they were recorded. Each subject developed a characteristic pattern of responses on these keys. terminated by a single response on the DRL key, and followed by reinforcement. In contrast, responding was erratic during the first (operant level) and the final (extinction) phases of the experiment. Kapostins (1963) reinforced the verbal responses of college students according to one of five DRL schedules: 7, 17, 27, 37, or 47 seconds. The subjects were required to say words and a selected word was reinforced if it was emitted at intervals which met the criterion of the DRL in operation. Systematic patterns of behaviour occurred between the reinforced responses. Some subjects repeated the same chain of words, some changed the pitch of voice in a cyclical fashion, and some stopped emitting words apart from the reinforced ones but reported counting between the verbal responses.

Several other investigators have also noted the development of collateral behaviour in the course of DRL training. In their study concerned with the effect of punishment Holz, Azrin and Ulrich (1963) observed that the behaviour of one pigeon differed from the others. This bird paced to the back of the box between responses and consequently obtained a sharply increased number of reinforcements.

Two studies in the literature report extensive analyses of collateral behaviour, taking advantage of its occurrence in the course of other experiments (1). During an investigation of E.E.G. changes related to performance under DRL and free-operant avoidance schedules, Hodos, Ross and Brady (1962) observed that movements of the monkeys caused artefacts, with apparent regularity, on the E.E.G. records. The schedule consisted of 15 minutes of DRL 21 sec. TO, avoidance (R-S=S-S=20 sec), and TO which cycled in that order in daily 6-hour sessions. One monkey made head movements during all the components. IRT distributions of these movements were rectangular during avoidance and TO but had a peak at 1-2 sec interval during DRL. After administration of pentobarbital (12 mgm/Kg) the head movements almost disappeared and DRL performance deteriorated. Administration of d1-amphetamine (3 mgm/Kg) altered the IRT distributions of head movements during avoidance and TO so that these resembled the distribution previously seen only in DRL. The IRT distribution of the lever responses on DRL shifted towards the shorter IRT's. In the second monkey

(1) "... a first principle not formally recognised by scientific methodologists: when you run onto something interesting, drop everything else and study it" (Skinner, 1959, p. 263). the collateral behaviour consisted of licking the holder of the water bottle. The temporal distribution of the trains of licks and their temporal relations to the lever responses were distinguishable under the three components of the schedule. IRT distribution of licking was similar to IRT distribution of lever presses on DRL; longer trains of licks occurred during avoidance responding and licking appeared to be random during TO. Pentobarbital and <u>dl</u>-amphetamine had similar effects: both the collateral behaviour and the responses were suppressed in DRL and TO. During avoidance the response rate declined byt all shocks were successfully avoided.

In the second of these studies Laties, Weiss, Clark and Reynolds (1965) observed an example of collateral behaviour in a rat. The animal had been responding on a mult. DRL 30 sec FR 30 with TO 2 min separating the components at every change. Collateral behaviour emerged after about 35 experimental hours and consisted of the rat "biting its tail and moving its mouth over the surface from one end to the other while holding the tail in its front paws" (p. 108). This behaviour occurred only when DRL was in effect. Duration of mouth-tail contacts and IRT's were positively correlated; the longer the mouth-tail contact the higher the probability that the next The effects of the response would be reinforced. following experimental manipulations were studied: (i) extinction and reconditioning; (ii) removal of the lever; (iii) suppression of mouth-tail contacts;

and (iv) administration of amphetamine sulphate. The mouth-tail contacts were suppressed by painting the tail with cycloheximide. In extinction the mouth-tail contacts as well as the responses became erratic and the former ceased after about 10.5 minutes; both types of behaviour recovered almost immediately after the first reinforcement in reconditioning. Removal and presentation of the lever gained discriminative control over the collateral behaviour so that it occurred only in the presence of the lever. When the collateral behaviour was suppressed, DRL performance became disrupted, with the result that fewer reinforcements were obtained. The mouthtail contacts disappeared 10 minutes after the administration of amphetamine sulphate (0.5 mgm/Kg) and then occurred rarely; in parallel with this the frequency of short IRT's increased.

Nevin and Berryman (1963) reported a study in which pigeons were reinforced on a two-key DRL procedure. A response on the first key turned off the light on that key and simultaneously illuminated the second key. A response on the second key was reinforced if a minimum of 2 sec had elapsed since the first response on the first key. When the second key was illuminated a response on that key, whether reinforced or not, turned off the light on that key, illuminated the first key, and thus recycled the procedure. Responding on an unlit key

had no programmed consequence. The relative frequency distributions of the intervals between a first response on the first key and the next response on the second key showed a sharp peak just above 2 swc; 80% of these intervals were followed by reinforcement. All birds continued to respond on the first key although the first response in such a run illuminated the second key. Durations of these response runs often met the DRL criterion for reinforcement on the Further, the probability of shifting second key. to the second key was an increasing function of the length of the response run on the first key. The persistence of these response runs was remarkable in view of the fact that they were never directly reinforced and never formed a part of the contingencies imposed by the experiment. It is clear that they mediated the temporal spacing of the responses required for reinforcement. These responses, however, occurred with remarkable regularity. Analysis of their IRT's showed that the relative proportion of IRT's in the 0.15;0.3 sec class was 0.75 and only two other classes of IRT's occurred. one on either side of this mode. As Nevin and Berryman point out, "temporal discrimination of one response may be based on the length of a chain of other responses, (but) the finding that the latter responses may themselves be regularly spaced in time leads to an infinite regression" (1963, p. 113).

51

The evidence is clear that regular, somewhat stereotyped, collateral behaviour or chains of responses can be observed to intervene between temporally spaced responses. But there is evidence that temporal discrimination may also occur in the absence of such behaviour. Anger (1956), and Kelleher, Fry and Cook (1959) were unable to observe collateral behaviour in their experiments. Belleville, Rohles, Grunzke and Clark (1963) described the behaviour on a four-component, threelever multiple schedule, of chimpanzees two of which were later used in space flights. They reported that superstitious responding involving the irrelevant levers did occur, but on the FR component. During the DRL component some responses were made on the levers other than the one related to the schedule but such responses initiated a further pause before a correct response. There were no chains of responses between the DRL responses although the DRL performance was highly efficient.

Some of the studies of collateral behaviour have taken advantage of the fact that this behaviour occurs in some of the subjects (e.g. Laties, Weiss, Clark and Reynolds, 1965); it does not however, occur in all of the subjects exposed to the same experimental conditions. It seems that overt, stereotyped behaviour often develops in the course of DRL performance and that when it does it contributes to the efficiency with which responses are spaced in time. But it is not a necessary condition of temporal discrimination. Of course, as Hodos, Ross and Brady have pointed out "there is ... no reason to suppose that the collateral responses observed ... represent(ed) anything more than a fraction of some more complex pattern. Such a pattern might be further composed of respiratory responses and small movements of skeletal musculature" (1962, p. 479). This is to raise once again the question of whether there are time-correlated events within the organism.

CHAPTER 4.

FIXED-INTERVAL SCHEDULES

OF REINFORCEMENT.

In fixed-interval schedules of reinforcement a response is reinforced only if a specified interval has elapsed since the previous reinforced response. Unlike the DRL contingency, however, responses which occur between reinforcements do not re-cycle the interval. The start of an interval may be timed in either of two ways: (i) from the previous reinforcement, or (ii) "by the clock", i.e. from the end of the preceding interval irrespective of the occurrence of reinforcement.

As Ferster and Skinner (1957) have pointed out, in effect there is little difference between the two procedures. If the interval is timed from the preceding reinforcement none of the inter-reinforcement intervals will be smaller than the schedule specification but some will be greater. Consequently the mean inter-reinforcement interval will be somewhat greater than the minimum interval specified by the schedule. If the FI is timed by the clock the mean inter-reinforcement interval will coincide closely with the schedule specification since some of these intervals will be smaller and some greater than the interval designated by the schedule.

Behavioural effects of FI, one of the four basic schedules of reinforcement in operant conditioning⁽¹⁾ (Skinner, 1938; Ferster and Skinner, 1957), has been studied extensively. No attempt will be made here to review this vast body of literature. Characteristics of FI performance will be considered and the subsequent discussion will be limited to relatively recent studies, in particular to those specifically directed at the analysis of temporal control in FI performance.

A. PATTERN OF BEHAVIOUR.

FI schedules generate a characteristic pattern of responding, typically consisting of a relatively long post-reinforcement pause followed by a gradually accelerating rate of responding. The response rate reaches a stable high level which is terminated at the

(1) Variable-interval (VI), fixed-ratio (FR), and variable-ratio (VR) are the other basic schedules of reinforcement. FI was termed "periodic conditioning" in the Behaviour of Organisms (Skinner, 1938).

55

next reinforcement. This pattern is called the FI scallop. **S**Typical cumulative records of FI performance is shown in Figure 5.

The pattern of responding in any one interreinforcement interval of FI may be conveniently considered in two parts: (i) the post-reinforcement pause; that is, the period which follows reinforcement and in which little or no responding occurs, and (ii) the responses in the remaining period.

1. Post-reinforcement pauses.

The occurrence of relatively long postreinforcement pauses in FI performance may, in part, be attributed ot the discriminative function of reinforcement. Responses which closely follow reinforcement are never reinforced and thus the probability of such responses is very low. It is important to note, however, that reinforcement is an event which signals the onset of the interval during which little or no responding occurs; a pertinent question is what determines the duration of the pause.

According to Ferster and Skinner (1957) behavioural events associated with reinforcement, such as consummatory behaviour which involves eating, cleaning etc., are important in the control of this duration. These events "constitute an occasion upon which a response is never reinforced" and "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 Figure 5 Typical cumulative records obtained from a rat under FI 1 min (upper two segments) and FI 3 min (lower two segments).



rat) which may also control a low rate of responding because of its relation to non-reinforcement" (p. 135). Although it may be the case that stimuli of this kind last as long as the post-reinforcement pauses, there is no independent evidence to support such a Moreover, this hypothesis can not explain hypothesis. the positive correlation which exists between the duration of the post-reinforcement pauses and the duration of the intervals specified by FI. Ferster and Skinner (1957) noted that the effect of reinforcement as a stimulus tends to last for a specific period, for example, roughly 30 seconds for pigeons. After this period"the effect is to start a new interval with a period of zero or very low rate of responding" Given that an initial portion of the post-(p. 135). reinforcement pause is occupied by stimuli associated with reinforcement, the problem remains of explaining what determines the duration of the remainder of this pause.

That there is a correlation between the duration of post-reinforcement pauses and the interval specified by FI may be seen by a comparison of the data provided by the large variety of studies in the literature. Figure 6 shows the results of intra-subject comparisons obtained in an experiment by the present writer. In this investigation the apparatus to be described in Part II was used; two three-month old, male hooded rats served as subjects. The animals were given access to food for 2 hours in every 24 hours;



Figure 6 Mean durations of post-reinforcement pauses in single sessions under FI 1 min, 3 min, 5 min, and 7 min. Data from 2 rats are shown. The point for FI 10 min was obtained from data presented by Ferster and Skinner (1957).

the experiment commenced when the weights became stable at approximately 220 gm. During initial training dipper-approach and lever-press responses were shaped. This was followed by 100 reinforcements on continuous reinforcement (crf). Subsequently, one animal was placed under FI 1 min, FI 3 min, FI 5 min, and FI 7 min in consecutive blocks of 20 daily two-hour sessions, in that order; the order of the schedules was the reverse for the second animal. Figure 6 shows for each animal the mean durations of post-reinforcement pauses in the final session of each block. For comparison, the result obtained by Ferster and Skinner (1957, p. 173, Figure 174) from a rat under FI 10 min is also included. The latter value was calculated by measuring the cumulative records provided by the authors and therefore it represents a rough estimate⁽²⁾. It is seen that there was an almost linear relationship between the durations of the post-reinforcement pauses and of the intervals of FI. Moreover, the point obtained from Ferster and Skinner's

(2) The data points obtained from this writer's experiment also lack complete precision. Although the intervals between responses were recorded on punched tape with a resolution of 0.01 sec the end of each post-reinforcement pause was judged merely by inspection of the print-out obtained from the tape. The problem of establishing objective criteria for fixing the terminal point of a post-reinforcement pause will be referred to later. (1957) data falls approximately on this line. Nevertheless the post-reinforcement pauses increase more slowly than the FI values, and the results of other studies indicate that the relationship may be negatively accelerated (cf Cumming and Schoenfeld, 1958). For the present discussion the important point is that there is an orderly relationship. Some point in the course of an interval seems to be discriminated so that the post-reinforcement pause gives way to responding.

2. Number of responses per interval.

Once stable responding on an FI schedule is established the overall pattern of behaviour is constant; and it will therefore be expected that the number of responses emitted in each inter-reinforcement interval will also be constant. Ferster and Skinner (1957) point out, however, that "since this condition (constancy of the number of responses per interval) depends in a sensitive way upon the 'triggering' of the acceleration to a higher rate, the number of responses at reinforcement will vary considerably" (p. 134). Another source of this variability is that even in well established FI performance occasional instances occur when the organism pauses throughout the interval and thus a single response is followed by reinforcement. Examples of this are shown in Figure 7. Such occasions would tend to result in a



Figure 7 Cumulative records of performance on FI 1 min to show examples of intervals in which few or no responding occurs - a, b, c, d, and e.

lowering of the number of responses emitted in each interval . An opposite trend may also operate, however, and this trend may be due to the establishment of a relationship between a given number of responses and reinforcement. If such a number contingency is established then the subject may tend, within limits, to respond at a high rate, i.e. emit the number of responses usually followed by reinforcement in a shorter period of time. Responding would then continue until the next reinforcement and thus the total number of responses emitted in the interval would tend to be higher than before. Of course, this would in turn upset any number relationship which may have been established. On the basis of such considerations an overall oscillation might be expected in FI responding.

The cumulative records from Ferster and Skinner (1957, p. 173, Figure 174) which were used to measure the durations of the post-reinforcement pauses, were also used to estimate the number of responses emitted by the rat in successive intervals of FI 10 min. The results are plotted in Figure 8. It will be seen that the variability was over a range of approximately 160-320 responses per interval.

The main purpose of the present writer's experiment described in the preceding section (p.58 ff) was to estimate the variability of the number of responses


Figure 8 Data from Ferster and Skinner (1957) re-plotted to show the number of responses emitted by a rat in each interval of FI 10 min. Intervals in which only 2 or 3 responses occurred wascomitted.

emitted in each interval of FI⁽³⁾. Figure 9 shows the number of responses emitted by one rat in the final 10 consecutive intervals of the final sessions under FI 1 min, FI 3 min, FI 5 min, and FI 7 min. For each animal the mean and standard deviation of the number of responses per interval, in the final three sessions under each of the four FI schedules is shown in Figure 10. The mean number of responses emitted per interval was an increasing function of the duration specified by the FI schedule. Moreover, there was a similar relationship between the variability of the number of responses and the duration specified by the FI schedule: the greater the value of the schedule, the greater the variability. The overall variability was less in this study than in Ferster and Skinner's (1957) experiment. the latter data, however, were based on as few as 🚏 intervals and the rat used in that study had a more varied experimental history. Further, in that study pellets were used whereas the reinforcer in the present experiment was liquid.

The results presented here do not reveal any previously unknown relationship, but they confirm, on the basis of an intra-subject analysis, the

(3) The "responses per interval" measure is used in the studies of progressive-interval performance to be reported in Part II. The present datawere sought in order to provide a basis for comparison of responding on PI and FI schedules.



Figure 9 Number of responses emitted by one rat in the last 10 consecutive intervals of the final sessions under FI 1 min, 3 min, 5 min and 7 min.



Figure 10 The mean (bars) and standard deviation (lines superimposed on bars) of the number of responses emitted by two rats, in each interval of FI 1 min, 3 min, 5 min, and 7 min. The figures were computed from data obtained in final three sessions under each schedule. findings of the numerous studies of FI performance. In general, it emerges that the duration of the interval specified by FI affects both the postreinforcement pause and responding so that, when the value of FI is increased, behavioural adjustment involves increases in the post-reinforcement pauses as well as the number of responses emitted per interval. Thus, the point in the course of an interval at which responding is "triggered" shifts along the time axis as the FI is made longer, but the extent of this shift is less than the increase in the value of FI. Of course, the relationship is further complicated by changes in the terminal rates of responding.

3. Problems of measurement.

Although it has been assumed in the above discussion that the two parts of the pattern of responding are distinct, to identify the point at which the post-reinforcement pause ends and responding begins, presents a difficult problem. For example, the segment of the cumulative record which is identified by inspection as the post-reinforcement pause often contains one or more responses (Figure 5). The first response (or a brief burst of responses) after reinforcement may be followed by a pause of appreciable duration and may be closer in time to the preceding reinforcement than it is to the next response. Further complications arise when two or more instances

of such isolated responses occur in the same FI segment. For these reasons it is not entirely satisfactory to take the first response emitted after reinforcement as the end of the post-reinforcement pause. Of course, a criterion could be established so that when, for the first time, two responses are emitted with an IRT of less than a given duration, the first or the second of these responses could be deemed to be the terminal point of the post-reinforcement This too, however, is not altogether pause. satisfactory because subsequent responding will on occasion, be interrupted by a pause considerably longer than the IRT designated the criterion. Moreover this difficulty is not overcome by specifying a relatively long IRT as the criterion, since the criterion will then be met early in the course of the post-reinforcement pause. Often, a further pause will extend beyond the response which met the criterion.

Considerations of the kind discussed above have led several investigators to develop alternative methods to measure performance under an FI schedule. One of these is the <u>quarter-life</u> measure proposed by Herrnstein and Morse (1957). This "is the time taken, in any one interval, for the first one-fourth of the total number of responses in that interval to be emitted (Herrnstein and Morse, 1957, p. 931).

A second measure, the mathematical <u>index of</u> <u>curvature</u>, was developed by Fry, Kelleher and Cook (1960)

and reflects the extent to which the FI scallop deviates from a straight line. Figure 11 illustrates the assumptions underlying this index. The theoretical straight line OY is obtained by joining the points of two successive reinforcements and thus represents the cumulative record which would be obtained if the rate of responding were constant throughout the interval. Basically the index of curvature is the result of the comparison of the area under the straight line with the area under the actual cumulative record. The latter area is estimated by assuming straight lines between Oa', a'b', b'c', and c'Y. The points a', b', and c' are obtained by dividing the time axis (the abscissa) of the curve into four equal parts (Oa, ab, bc, and cX) and by drawing perpendicular lines which intersect the cumulative record. Thus, the index of curvature is computed by subtracting the area Oa'b'c'YX from the area OYX. Consequently, the index reflects not only the extent but also the direction of the curvature. The following equation expresses the index (I):⁽⁴⁾

$$I = \frac{3R_4 - 2(R_1 + R_2 + R_3)}{4R_4}$$

⁽⁴⁾ Derivation of the formula is given, in detail, in Fry, Kelleher, and Cook (1960).



Figure 11 Cumulative-response curve drawn to illustrate geometrically the assumptions underlying the index of curvature (Reproduced with permission from Fry, Kelleher and Cook, 1960). where R_1 , R_2 , R_3 and R_4 are the number of responses emitted in the first, second, third and fourth quarters of the interval, respectively.

A further measure, proposed by Gleitman and Bernheim (1963), is the <u>half ratio</u>. This is obtained by dividing the number of responses emitted in the first half of the interval by the total number of responses in that interval.

Gleitman and Bernheim (1963) used the halfratio measure in a study of retention of FI performance Herrnstein and Morse (1957) and Fry, in rats. Kelleher and Cook (1960) provided data from studies of the effects of drugs on FI performance, to demonstrate that the quarter-life measure and the index of curvature are sensitive to changes in responding on FI. More recently Gollub (1964) reported a study of the relations among these measures. In that study the quarter-life was modified slightly and expressed as a percentage of the total duration of the interval whereas the measure proposed by Herrnstein and Morse (1957) was in absolute units of time. The modification facilitated comparison of results obtained from different intervals.

Gollub (1964) found that all three measures were very highly correlated. Figure 12 shows the almost linear relation between the index of curvature and the quarter-life. The rank order correlations

were always greater than 0.8; in most cases they were greater than 0.9 and on rare occasions slightly



Figure 12 Scattergrams from one session for each of four rats with values of the Index of Curvature plotted against quarter-life for each interval (Reproduced with permission from Gollub, 1964).

less than 0.9. Moreover, these measures were correlated only to a moderate degree with the average rate of responding. Thus, it is evident that in order to describe FI performance the rate measure must be supplemented by a measure which reflects the temporal distribution of responses. It appears that the three measures described above are very similar in the extent to which they fulfil the latter requirement. Although they may. therefore, be used more or less interchangeably, selection of one on the basis of further criteria is desirable. Gollub (1964) suggested that " the criteria that would recommend one above the other measures for any particular experiment are: (i) communication value, or ease of understanding; (ii) ease of computation; (iii) sensitivity to change by an independent variable; and (iv) variability when data should be stable" (p. 343). On the bisis of the first two of these criteria the half-ratio and the quarter life have an advantage over the index of curvature. Gollub's (1964) results showed that the index of curvature was somewhat more variable thin the quarter-life when both were applied to same data Moreover, since the half-ratio is a more gross measure than the quarter-life it would seem reasonable to assume that the latter is more sensitive to change by an independent variable. For these reasons quarter-life emerges as best of the three.

74

For these reasons the quarter-life measure will be used in the analysis of the results presented in Part II.

B. EXPERIMENTAL MANIPULATIONS.

In this section we shall consider the effects on FI performance of manipulating some independent variables. Ferster and Skinner (1957) have described in detail the development of responding on FI, and the effects of such experimental manipulations as the introduction of TO probes, the provision of added stimuli (external clocks), and the like. In the present discussion the emphasis is placed on the results of more recent investigations, published since Ferster and Skinner's (1957) work.

1. Aversive stimulation.

When a punishment contingency is added to all responses maintained under an FI schedule the overall rate of responding decreases. Azrin and Holz (1961) trained pigeons to respond on FI 5 min; when the behaviour became stable the punishment contingency was introduced so that brief electric shock was administered at each response. A range of shock intensities from 30 v to 180 v was used in ascending order in blocks of daily sessions. It was found that the overall rate of responding was a decreasing function of the intensity of shock. At 30 v the rate declined sharply at first followed by gradual, almost complete recovery to the previous rate. At 60 v the recovery was partial and at intensities above 60 v the low rates were maintained with no indication of recovery. On the other hand, the temporal distribution of responses in each interval of FI was not affected by the punishment contingency. The introduction of shock resulted in the reduction of the terminal as well as the initial rate of responding, and the characteristic scallop was retained at all intensities. Moreover, there was no appreciable change in the quarter-life and the index of curvature at different shock intensities.

With reference to the results of their studies of the effects of punishment on performance under other schedules of reinforcement, Azrin and Holz wrote: "The changes produced by punishment in the temporal patterning of performance appear to be characteristically different for different reinforcement schedules" (1961, p. 346). It was seen in the previous chapter (p.38) that the addition of the punishment contingency to a DRL schedule resulted in the reduction of the relative frequency of responses with very short IRT's, and in a related increase in the frequency of reinforcement. Thus it appears that punishment affects selectively the non-reinforced responses when a concomitant increase occurs in reinforcement frequency; when, as in the case of FI, the frequency of reinforcement is unaltered no such

selective effect of punishment is observed.

Aversive stimulation was used in a different way in a study by Morse and Kelleher (1967). These investigators presented unavoidable shocks at regular intervals to monkeys, in the presence of a visual stimulus. Responding in the presence of that stimulus resulted, according to a schedule of reinforcement, in the termination of the stimulus and of the Several mult FI FR shocks for a given TO period. schedules were used in a series of experiments with the general finding that the patterns of responding characteristic of FI (as well as FR) developed under these conditions. Morse and Kelleher concluded that "the schedule of reinforcement is more important in the control of behaviour than is the nature of the reinforcer" (1967, p. 286).

2. Interaction with other schedules.

Although typical patterns of responding appropriate to the schedule of reinforcement in operation do emerge when two or more schedules are programmed to alternate, the effects of the schedules may nevertheless interact to a certain extent (e.g. Ferster and Skinner, 1957; Kelleher, 1966). Hanson, Campbell, and Witoslawski (1962) investigated the effect of manipulating the duration of the FI component in a chain FI FR schedule of reinforcement. The value of FR was 20 throughout the experiment with FI 2, 4, 8, or 16 min presented in random order in blocks of daily séssions; the FI was changed after the rat's

behaviour remained stable in five successive sessions. The results showed that under these conditions the effect was confined almost entirely to FI performance. The number of responses emitted in the FI component per reinforcement was an increasing function of the duration of the interval specified by that schedule. The relationship was inverse in the case of postreinforcement pause; the longer the FI, the shorter the proportion of the interval occupied by the post-reinforcement pause (cf p.58 ft). Further, the overall temporal distribution of responses differed under different FI's. Under FI 2min. for example, a relatively long post-reinforcement pause was followed by abrupt transition to a high terminal rate; under FI 16 min a proportionally short post-reinforcement pause gave way to gradual acceleration to the terminal rate. The index of curvature reflected these changes. It is interesting to note here that this measure correlated highly with a measure of the post-reinforcement pause used by the The latter was obtained by recording experimenters. cumulatively the time between each reinforcement and the next response in a session and by dividing the total by the number of reinforcements in that session. The result was then expressed as a proportion of the value of FI.

Although in the above experiment changes in the duration of FI did not affect responding on FR, interaction of the components is often observed in similar complex schedules. For example Kendall (1967)

78

reported that when FI was the final component in a two-component chain schedule, the rate of responding in the first, VI, component was related to the duration of FI. In that study pigeons responded under a chain VI FI schedule; VI 1 min was followed by a sequence of two FI's, each terminated by primary reinforcement, but the overall rate of reinforcement was kept constant. The values of FI's, in pairs and in that order, were as follows: FI 0.25 min FI 1.75 min; FI 1 min FI 1 min; FI 1.75 min FI 0.25 min. The results showed that the rate of responding on VI was inversely related to the duration of first FI. In each component the pattern of responding was characteristic of the schedule in operation. Moreover. although in the final component no stimulus change (apart from reinforcement) accompanied the switch from one FI to the next, the behaviour nevertheless changed appropriately. The rate of responding was higher under FI 0.25 min than under FI 1.75 min, irrespective of the order of the schedules.

In a complex schedule which consists entirely of FI components the rate and temporal pattern of responding is determined in part by the overall relations involved in the schedule and in part by the local effects of the components. The extent to which the individual components control behaviour depends largely on the prevailing stimulus conditions. Kelleher and Fry (1962) studied the performance of pigeons in a schedule consisting of three FI components in a tandem (tand) and a chain arrangement.

In both of these schedules reinforcement occurred when the three components were completed; the difference was that in the tandem schedule the stimulus situation remained unchanged between primary reinforcements, whereas in the chain schedule a different stimulus was correlated with each component. The stimuliswere arranged in two different ways: (i) stimuli were correlated with the three components in a fixed sequence (chain FI FI FI); (ii) stimuli were in a variable sequence so that one stimulus was sometimes correlated with the first component, sometimes with the second, and so on (var chain FI FI FI). Either of two sequences of FI values were used: FI 1 min FI 1 min FI 1 min or FI 1.5 min FI 1.5 min FI 1.15 min. Since the tandem schedule involved no stimulus change in any one sequence, each sequence could be considered as a single unit of FI; in fact under this schedule responding was positively accelerated between primary reinforcements. Under chain FI FI FI very long pauses occurred in the first component; responding was positively accelerated in the second and third components but the rate was considerably higher in the latter. In var chain FI FI FI positively accelerated responding, typical of FI performance, occurred in every component.

It appears that the development of the FI scallop is related to the occurrence of reinforcement, as such, whether conditioned or primary, at the termination of the scallop. In chain FI FI FI the first two stimuli were reliably correlated with non-reinforcement and, as Kelleher and Fry (1962) point out, they functioned as discriminative stimuli. Responding in the presence of the first of these stimuli and terminated by the second was not scalloped although the schedule in effect was FI⁽⁵⁾. Reinforceemnt always occurred in the presence of the third stimulus and this was a conditioned reinforcer; responding in the second component led to the occurrence of this conditioned reinforcer and was scalloped. On the other hand, in var chain FI FI FI each stimulus was occasionally paired with primary reinforcement and the positively accelerated pattern of responding occurred in each component.

In the case of the chain as well as the tandem schedule in this study, the total duration of a sequence may be considered as a single interval of FI. According to this formulation the chain involved a FI schedule with the addition of three consecutive time-correlated stimuli (which were responsecontingent). The effects on FI performance of the addition of such stimuli will be considered in the next section.

(5) Of course, the second stimulus is followed by the third stimulus (a conditioned reinforcer) and may therefore acquire, to some extent, the properties of a conditioned reinforcer. It is, however, also a stimulus in the presence of which primary reinforcement never occurs. This latter relationship is in a sense more immediate and the consequent discriminative stimulus function would be expected to be dominant.

3. Added "clocks"

Ferster and Skinner (1957) suggested that "To the extent that the bird's behaviour is an event varying in time and correlated consistently with the FI schedule, it can be thought of as a clock by which the bird may modify its behaviour with respect to reinforcement" (p. 266). We shall see in a later section, however, that interruptions of this behaviour (or this "clock") do not disrupt the basic characteristics of FI responding. The point of interest for the present is that Ferster and Skinner "attempted to get some notion of the control exercised by the bird's own behaviour by adding an external stimulus that varies uniformly in some dimension during the fixed interval" (1957, p. 266)⁽⁶⁾. In their experiments a visual stimulus was used, the size of which increased continously throung the fixed interval and reset to its initial size at reinforcement. That this stimulus gained control over behaviour was demonstrated by such manipulations as reversing the direction of change and maintaining the cycles of the stimulus in extinction.

An experiment by Segal (1962) using discrete, rather than continuously changing, stimuli provides some evidence on the nature of temporal control in FI performance. In this study pigeons were exposed to three FI schedules (FI 12 sec, 1 min and 5 min).

(6) Such stimuli have been termed "external clocks", "added clocks", or "added stimuli".

In the course of an interval of a schedule the colour of the light illuminating the response key was changed at every one-fourth of the interval: The final colour remained on until reinforcement; the cycle then re-started with the presentation of the first light. Either of two conditions were imposed, viz. in one, each colour was presented independently of responding in the course of the interval; in the other, the key was illuminated briefly only when a response occurred. Under the first of these conditions a dsicrimination developed so that there was almost no responding during the early lights. When the schedule was FI 1 min the terminal rate of responding started abruptly at the presentation of the fourth light. In FI 5 min, however, the terminal rate was reached gradually after the presentation of the fourth light. Thus, there was evidence of temporal discrimination superimposed upon the visual discrimination. Moreover, when the presentation of lights was made contingent on responding an intermediate behaviour, between the performance under the previous condition and base-line FI The behaviour was intermediate responding, developed. with respect to the absolute number of responses per interval as well as the percentage of responses per quarter of the fixed interval. Segal (1962) suggested that if, in addition to being discriminative stimuli, the early lights are assumed to be negative conditioned reinforcers and the later lights, positive conditioned reinforcers, then responding in the presence of the dark key was reinforced sometimes negatively

and sometimes positively - and on regular occasions by primary reinforcement. According to Segal, "The resultant performance, then, was the algebraic sum of several sources of strength - some positive, some negative, some exteroceptive, some proprioceptive, and some interoceptive (pure "timing" cues)" (1962, p. 57). The assumption that all of the four stimuli became conditioned reinforcers may not be warranted, especially in the light of the experiment by Kelleher and Fry (1962) which was discussed above. It is evident, however, that where exteroceptive cues were available they became preportent in the control of behaviour. But that other temporal factors were nevertheless involved in FI responding was shown by the devleopment of scallops in the course of an exteroceptive cue, given that the duration of the cue was sufficiently long.

Further evidence that even though added stimuli are present the temporal distribution of responses is nevertheless partly related to some other factor or factors, was provided by Ferster and Zimmerman (1963). In this study auditory, visual, and auditory and visual stimuli were used as external clocks. It was found that under three different schedules, namely mult FI 10 min FR 80, FI 4 min, and FI 4 min LH 5 sec, thesus monkeys responded with remarkable precision. Unlike the high and sustained rates of responding which are usually observed "at the optimal clock settings, the monkeys' rates were so low that many reinforcements

occurred with a single response" (Ferster and Zimmerman, 1963, p. 321). In the final experiment of this study FI performance in the presence of the three types of clocks as well as in the absence of a clock was compared. Two four-component multiple schedules were used; all components were FI 6 min LH 5 sec in one schedule, FI 12 min LH 5 sec in the other. The prevailing stimulus situations in the four components were: (i) no clock; (ii) auditory (iii) visual clock; and (iv) auditory and clock; visual clock, in that order. In general, the stimulus control was closer with the combined auditory-visual clock and the visual clock than with the auditory clock. Responding in the absence of a clock was on occasion scalloped, but often it was suppressed and the subject failed to respond during the LH period. Thus, the stimuli were clearly important in the control of behaviour. The remarkable precision of responding in the presence of the stimuli, however, and notably the fact that often a single response, followed by reinforcement, occurred in the brief LH period suggest that several sources of control are likely to be involved in this situation⁽⁶⁾.

(6) One important variable was the species used in this study. Numerous studies have demonstrated that monkeys respond with considerably greater precision under temporally based schedules than do pigeons (cf p. 40%).

The studies discussed above agree in suggesting that behaviour remains unaffected by stimuli in the early part of an interval. In the middle portion of the interval the effect is mainly that of suppressing responding, in the sense that the post-reinforcement pause is appreciably longer in the presence of a clock than it is when no stimuli are provided. Further. responding accelerates sharply when a critical clock time (i.e. a given stimulus value) is reached. These findings are also observed when only a single, non-varying stimulus of brief duration is presented at different points of the fixed interval. Farmer and Schoenfeld (1966) trained pigeons to respond under FI 1 min and when behaviour became stable they presented a visual stimulus for 6 seconds, once in every interval. The position of the stimulus, in one of ten equal portions of the interval, was changed systematically over 84 daily sessions. When the stimulus was in the early part of an interval the temporal distribution of responding was similar to that obtained without the stimulus. Responding was reduced immediately before the stimulus when it was presented in a later portion of the interval, followed by a sharp increase in the rate which continued until reinforcement. Thus, two scallops emerged in the course of a single interval; one before and one after the stimulus. As Farmer and Schoenfeld (1966) pointed out, this is similar to the results of those studies in which a pattern of several successive scallops, associated with successive

stimulus changes, emerges.

In a second experiment reported the same study the stimulus was presented twice in each interval, viz. once as described above, and once in the final portion of the interval so that reinforcement always occurred in its presence. In these conditions the pigeons responded during both stimuli and paused when neither was present. Apart from this discriminative control, however, a further relationship The greater the temporal distance of the emerged. first stimulus from reinforcement, the smaller was the number of responses emitted during that stimulus. Farmer and Schoenfeld (1966) pointed out that this was a generalisation effect along a temporal continuum. It was, of course, also evidence of temporal discrimination, interacting with the discriminative control by the stimuli.

The technique of presenting discrete stimuli in the course of an interval of FI has also been used in investigations of the role of mediating behaviour in the development and maintenance of FI performance. Studies directed at this problem will be discussed in the next section.

C. MEDIATING BEHAVIOUR.

Although the gradual increase in response frequency in the course of an interval is generally

taken to be evidence of temporal discrimination, the pattern can also be explained in terms of mediating behaviour (cf Ferster and Skinner, 1957, p. 134); this is the same kind of explanation as that given in terms of collateral behaviour in the case of DRL performance (p.46 ff). Since in FI regular responding occurs between the reinforced responses, the suggestion is that in each interval the responses constitute a chain. "A chain of responses (or a response chain) is a response sequence in which each response either functions as a discriminative (or eliciting) stimulus or produces a discriminative (or eliciting) stimulus controlling the response that follows" (Kelleher. 1966; p. 163). The reason for the maintenance of the chain is that its final component is reinforced.

Although the explanation that responses in a fixed interval form a chain appears to have the advantage of parsimony, it leaves one aspect of the scallop to be accounted for: the relatively long post-reinforcement pause. It was seen above (p.56 ff.) that the duration of post-reinforcement pauses were correlated with the duration of the interval specified by FI. It appeared that some point in the course of the interval was discriminated so that the postreinforcement pause gave way to responding. Even if the responses constituted a chain, the temporal relation between the onset of this chain and the preceding reinforcement was regular.

Further, Kelleher (1966) has pointed out that "when it is assumed that a response sequence is a response chain, the stimuli in the chain are hypothetical. Hypothetical response-produced stimuli have enabled theorists to provide plausible accounts of many characteristics of response sequences, but there is no <u>a priori</u> reason for assuming that response sequences are response chains" (p. 163). One important question which needs to be answered is whether the apparent temporal discrimination in FI performance is dependent on the supposed response chain of the scallop: does disruption of the response sequence disrupt the characteristic FI behaviour?

In their studies of FI performance Ferster and Skinner (1957) occasionally interrupted the responding of pigeons by introducing S^A periods. Lights in the experimental box were switched off during S^A. In one experiment 30-second S^A periods interrupted responding on FI 60 sec; in another up to 5-minutes of S^A interrupted FI 10 min. Although no responses occurred during S^A, the scalloped pattern of responding survived during the remainder of the interval.

In an extensive series of experiments Dews (1962-1966b) investigated the effect of multiple S A periods on FI performance. In the first of these studies (1962) pigeons were first trained on FI 500 sec To 250 sec; a house light (HL) was then introduced in alternate 50-second periods during every interval of the schedule. Each 500-second interval of the FI started with a 50-second period of no-HL so that the 5th HL presentation coincided with the final part of the interval. On

89

that occasion HL continued until reinforcement was obtained. The results are shown in Figure 13; the periods without HL disrupted responding in that the rate of responding was low on these occasions. However, a gradual increase in the frequency of responses continued to occur in successive HL periods. A similar tendency, at a much lower level, was also seen in the successive no-HL periods. Further, a "miniature" scalloped pattern of responding was evident in individual HL periods. In his second study Dews (1965a) replicated this experiment with a squirrel monkey and obtained similar results.

The third study (1965b) is of added interest because unusually long FI values, up to 27 hours, This study investigated the effects of were used. less regular and prolonged interruptions on FI performance. In the first experiment TO 50 sec FI 500 sec was interrupted by a single period of HL for 50 seconds; TO 540 sec FI 900 sec by two 180-second presentations of HL; and TO 300 sec FI 3000 sec by one HL which lasted 600 sec. Again, the scallops survived under all the conditions and the rate of responding was very low during S^A. Similar results were also obtained in the second experiment with FI intervals of 10.000, 30.000, and 100.000 seconds and alternating S periods of 1000, 3000, and 10.000 seconds; with these very long intervals reinforcement consisted of 10 successive magazine presentations on crf. In this experiment S^A was the presence of HL.

90



Figure 13 Mean rates in successive 50-second compartments of FI. The bar graphs show each bird singly, as labelled; the bottom row shows the simple arithmetic means, period by period, for the four birds (Reproduced with permission from Dews, 1962). Figure 14 shows cumulative records of individual FI segments under FI 30.000 sec and FI 100.000 sec. It is clear that over these very long intervals the gradually increasing tendency to respond was retained, and although the effect of the S^A periods was less obvious under FI 100.000 sec the related change in behaviour is nevertheless unmistakable.

The next in this series of studies by DEws (1966a) investigated the effect of presenting long S⁴ periods and brief S^D's. Pigeons were reinforced under FI 500 sec; S^{4} (HL) was presented throughout the interval except in two 50-second periods when no HL One of these S^D periods of 50 seconds was on. always occurred aththe end of the interval and continued until reinforcement. The position of the other was at one of consecutive 50-second segments of the interval. These "probe" sessions were separated by sessions in which S^{D} and S^{A} periods alternated. In the probe sessions fewrresp onses occurred during S^{A} ; the rates of responding in S^{D} was low in the early parts of the interval and a clear tendency was observed to respond at progressively higher rates when S^D was presented in latter parts of the interval.

Finally, Dews (1966b) investigated whether the results so far obtained were dependent on (i) extensive previous training on FI, and (ii) continued presence of the keylight which remained on during the S^A periods. He reported that pigeons placed directly on the S^A procedure also showed a gradually increasing tendency to respond in the course of an interval of FI schedule. Further, the tendency survived when



Figure 14 Cumulative records of two consecutive FI 30.000 sec (upper left) and two consecutive FI 100.000 sec (lower right). The thickened black segments on the abscissa show the periods of S⁴. (reproduced with permission from Dews, 1965b).

S^A was complete darkness.

The results of these studies are clear; the scalloped pattern of FI behaviour cannot be accounted for by reference to response chains. Dews has suggested that the appropriate explanation is in terms of the retroactive enhancing effect of reinforcement. For example, reinforcement which follows a response with a delay of some 100 seconds may nevertheless result in an increase in the future probability of that response (Dews, 1960). Such an effect would also operate in the FI situation so that those responses which precede the reinforced response would The extent of this effect would be strengthened. depend on the temporal distance between any one response in the scallop and reinforcement. However, Dews (1965b) adds that "the constancy of the FI pattern over large ranges of parameter value, with similar proportions of total responding occurring in successive segments of the intervals, shows that it cannot be the absolute delay of reinforcement of responding that determines the rate, but may be rather the delay as a fraction of the consistently imposed schedule cycle" (p. 435).

The absence of a direct relationship between delay of reinforcement and the probability of response suggests that this relationship may not be the only factor contributing to the FI pattern. Of course, a response can be reinforced only if it is emitted. The suggestion that the responses in an FI scallop are reinforced remotely by the subsequent reinforcement which terminates the interval, depends on the occurrence of these responses. One pertinent question is whether gradual increase in response probability in the course of an interval would still be observed, even when responses, other than the immediately reinforced response, are never permitted to occur in the history of the subject. A study by -Wall (1965) provides an answer to this question.

In this experiment rats were trained on a discrete-trial FI 60 sec procedure. During initial training a retracting lever was presented once every 60 seconds and a single response was followed by reinforcement and removal of the lever. The lever was available at each presentation, at first for 30 seconds and later for 5 seconds. In subsequent test sessions the lever was introduced once in the course of each 60-second interval as well as at the end of the interval. A response was reinforced only on the latter occasions. For different groups of rats the additional presentations of the lever occurred at 15, 30, or 45 seconds after the reinforced presentation. For a further group the non-reinforced presentation of the lever occurred at any one of these three intervals, in random order. It was found that the shortest response latencies, that is, the intervals between the introduction of the lever and response, occurred on reinforced occasions. The duration of the latencies

95

on how -reinforced occasions was an inverse function of time since previous reinforcement: as the availability of the next reinforcement approached latencies became shorter. This relationship was observed in the first part of the first of three test sessions; hence the results cannot be attributed to the effect of reinforcement on non-reinforced responses during these sessions. Inspection of the results, however, reveals some evidence of such an effect in the later test sessions. The shortest latencies remained unchanged, but the longer latencies, at 15 and 30 seconds after reinforcement, gradually decreased. The decline in latencies was sharper in the last test session.

Finally all groups were placed in extinction. For the group presented with the lever at 30 seconds from the previous reinforcement as well as every 60 seconds, extinction consisted of regular lever presentations. No differential responding was observed in these conditions. However, the other groups continued to respond with shorter latencies on those occasions when a response would have been reinforced in training, that is, at intervals of 60 seconds.

Unfortunately the results of this experiment have been presented in terms of groupeaverages averaged over trials or sessions. No data have been provided about the behaviour of individual subjects; and this seriously detracts from the value of the findings. The implication, however, is clear; the probability of responding increases in the course of an interval of FI even though such responses have never been reinforced remotely. It is also indicated, by the change in latencies in later test sessions, that delayed reinforcement is a factor in the development of FI scallops; this does not, however, fully account for this pattern of behaviour. The evidence, especially if it is confirmed by data from individual subjects, strongly supports the view that discrimination of the duration of intervals plays an important part in FI performance.

One fact which emerges from the studies discussed in the preceding chapters is that organisms show, in general, a remarkable ability to adjust to the temporal reinforcement contingencies imposed upon them. The finding by Dews (1965b), for example, that the FI scallop occurs in intervals of more than 27 hours is quite astonishing. A feature common to all these studies is that the intervals specified by a schedule, whatever their duration, are held constant. A pertinent question, however, is whether organisms can also adjust to temporally based <u>changes</u> in contingencies. The research to be described in the following pages was devoted to answering this question.

97

PART II.

CHAPTER 5.

PROGRESSIVE-INTERVAL

SCHEDULES OF REINFORCEMENT:

A. INTRODUCTION.

The schedules in which the temporal distribution of reinforcements undergoes gradual change are the progressive-interval (PI) schedules of reinforcement. These (as well as progressive-ratio schedules) were first used by Findley (1958) as components of concurrent schedules in a study concerned with "preference and switching".
Until the present, however, there have been no published reports on responding under a PI schedule⁽¹⁾. In PI schedules, as in FI, only the first response which is emitted in each of successive intervals of specified durations is reinforced. Further responses in an interval have no programmed consequence apart from the sound produced by the operandum and the like. Unlike FI, however, PI consists of intervals the durations of which are increased successively according to some rule⁽²⁾. In the experiments to be described in the following chapters two types of incremental series were used: arithmetic, and geometric progression.

In all the following experiments rats served as subjects and the same apparatus was used. In order to avoid later repetition the apparatus will be described here.

B. APPARATUS.

The experimental chamber, the programming and recording apparatus, and the living cages were housed in separate rooms.

(1) Brief papers on this topic were read by the present writer at two conferences (Harzem 1967a, 1967b).

(2) In Findley's (1958) experiments PI schedules involved arithmetic progression.

1. Experimental chambers.

Four standard operant conditioning boxes were used. The boxes were identical in all respects, apart from small differences which may have been introduced during manufacture, and therefore the details of only one are given. Photographs of the experimental chambers are shown in Figures 15a and 15b.

A box had a floor area of 20cm X 24.2cm and its height was 18.8cm (inside measurements). It was made of three bakelite walls lined on the inside with metal sheets; the fourth, a 20cm wide wall was formed by a removeable metal panel on which the lever (or two levers) and the reinforcement mechanism were mounted. The floor of the box was made of ten cylindrical metal bars, each with the diameter of 0.8cm; they were spaced equidistantly and parallel to the panel. The roof of the box was a perspex lid, which, when closed was held firmly in position by two folding flaps.

Centrally placed on the panel was a rectangular recess into which a motor-operated dipper delivered 0.05 mil diluted condenxed milk (50%). The recess was 4.4cm wide and 4.7cm deep, with a height of 6.2cm; its floor was level with the floor of





Figure 15a Photographs of one of the experimental boxes in position inside a sound attenuating chamber. For this purpose the "back" wall of the box was replaced by a perspex panel. The lever and the dipper recess are seen in the upper photograph and the lower picture indicates the size of the box in relation to a rat.



Figure 15b The rear view of the experimental box to show the dipper mechanism and the connections to the panel. the box. The dipper was normally "up"⁽³⁾; at reinforcement it was depressed into a container placed below it and returned to resting position. In the course of developing this dipper it was ascertained that the time taken by this movement, 0.5 sec, was less than that required by a rat to move from the lever to the dipper.

In either side of the recess, at a distance of 2.8cm edge-to-edge, were slots to which removeable levers could be fitted; when only one lever was used, the other slot was filled by a blank. A lever was 4.8cm wide and protruded 2.5cm into the box, 4.7cm above the floor. The construction of the lever was different from those commonly used in that it contained no microswitch. Two pins at the rear which limited the vertical travel of the lever were utilised as contacts of a solid-state bistable (or flip-flop) unit. One side of the bistable was "on"

(3) In most experiments which have used this type of mechanism the dipper is usually left in down position and raised for a specified period when reinforcement occurs. The arrangement used here appears to have the advantage that it introduces no temporal contingencies extraneous to the schedule of reinforcement used in an experiment. Some investigators have noted, however, that leaving the dipper up results in the occurrence of frequent approach responses (Hurwitz, 1967, personal communication). In the present case the motor produced a sound; this always signalled reinforcement and in its absence no frequent approaches were observed.

when the lever was in resting position; depression of the lever, that is, contact made with the uppermost pin, switched on the alternative output of the bistable. This output activated a one-shot pulser and the pulse was utilised by appropriate programming and recording units. The advantage of this arrangement was that a second pulse could occur only if the lever was returned momentarily to its resting position, thereby resetting the bistable. Thus, occurrence of extraneous pulses due to leverbounce and "contact-chatter" of the microswitch were avoided. A further advantage was that the lever could be set to operate at light pressures, as low as 2 gm. In the experiments reported here the minimum downward pressure required to depress the lever was set at 5 gm, and the vertical travel at the front end, at 2cm.

9.4cm above each lever slot was a circular light holder (diameter 1.6cm); these lights were not used in the experiments to be described.

Each experimental box was housed in a sound attenuating chamber the walls of which were made of layers of foam rubber and expanded polystyrene. The interior was lined with aluminium foil to reflect sound waves which light penetrate through the walls. The chamber was ventilated, and illuminated by a small house-light mounted on the ceiling. Two speakers were incorporated in the lid of the chamber; one was used to provide continuous white noise (60 db), and the other to present sound stimuli. Closure of the lid activated a switch which was used, in those experiments where this was appropriate, to activate the timing units and the like in the controlling circuitry, that is, to start the experimental session⁽⁴⁾.

2. Control units.

Three basic types of control units were used, all of which were solid state and involved no moving contacts: (i) logic elements, (ii) pre-determining timer/counters (decatron units), and (iii) custom built progressive-interval units⁽⁵⁾. The first two were mounted on standard busbars and could be "patched" appropriately to program an experiment (Figure 16). They worked from a 24 v, negative going supply. A master clock provided three separate pulse outputs: 1 per second, 10 per second, and 100 per second. These outputs were distributed to all sections of the busbar unit and could be connected to the timer/ counters, as required. Thus an interval could be timed by setting the pre-determining function of the timer/counter appropriately.

(4) This arrangement made it easy to reset to zero timers and the progressive interval unit, at the onset of a session. Thus, the control units were switched on before the animal was placed in the box and the session started when the lid was closed. Although an interval nevertheless elapsed between the two latter operations, it was optimally brief.

(5)

The units which programmed the arithmetic PI incorporated mechanical pre-determining counters.





Figure 16 Photographs to show the units which programmed the experiments. The upper picture shows the arrangement of one such program; the lower picture, the busbar unit. The progressive-interval units were custom built (Figure 17) and also utilised the input from the master clock. The unit "calculated" the number of clock pulses required for the current interval of the PI and when that number was matched by the number of clock pulses, it (i) gave an output pulse, (ii) "calculated" and "set up" the number of pulses required for the next interval, and (iii) restarted the count of input pulses from the master clock. The output pulse from the unit was used to "set-up" the next reinforcement.

In arithmetic PI units a constant increment for each interval could be programmed. In the case of the geometric PI unit the duration of, or the number of clock pulses required for, an interval was "calculated" by adding to the duration of the previous interval a certain proportion of it. The unit could be set for increments of any percentage in prime numbers. Of course, there was also provision to set the duration of the initial interval. A further facility was provided so that the input of a reset pulse re-started the unit at the initial interval.

3. Recording apparatus.

The two main kinds of experimental events, responses and reinforcements, were recorded on (i) cumulative recorders, (ii) mechanical counters, (iii) punched tape (Figure 19). In some experiments event recorders were also used.

The records on the punched tape were coded in Algol by a unit named SETAR⁽⁶⁾. This coded the responses, the reinforcements, and the setting up of the reinforcements (that is, the time when a new interval started) as numbered events; at the occurrence of any one of these, the number of the event and the time since previous event, with a resolution of 0.01 sec, were punched on the tape. The tape was directly passed through a reader coupled to an "input writer" which printed the results on These raw data provided immediate information paper. on the experiment in progress and were used later to calculate some of the findings to be presented. The punched tapes were subsequently processed by an Elliot 803 computer; the data thus obtained constitute the remainder of the results presented in the following pages.

4. Living cages.

The rats were housed singly in standard cages (Figure 18). At the back of each cage was a recess containing food pellets; the door of the recess was opened or closed by a synchronous motor. A central unit controlled the opening and closing times of the doors, and thus the duration of the availability of food per 24 hours. Water was available ad lib.

(6) This instrument had to be modified extensively.



Figure 17 A progressive-interval unit (lower picture) and the general arrangement of these units (upper picture).





Figure 18 The home cages of the animals.



Figure 19 The punched-tape unit in position in a sound insulating box.

The lights in the room which held the living cages were also controlled by a timing unit, and were on from 8 a.m. to 9 p.m. each day. This room had no windows and thus the 24 hourly light/dark cycle was held constant. The room temperature was 20° C.

C. METHOD OF DEPRIVATION.

The animals were weighed daily at the same time except at week-ends. Prior to the imposition of a food-deprivation regime, the average free-feeding weight of an animal was estimated over seven days. Subsequently the weight was maintained at 80% of this, plus or minus 5 gm. In all cases this was achieved by allowing access to food for 2 hours per 24 hours. If the animals weight exceeded the designated limits, the duration of food exposure was increased or decreased appropriately; such operations had to be carried out on only rare occasions.

For each subject the feeding time was armanged so as to allow an interval of approximately 1 hour from the end of an experimental session. This was to overcome the possibility that the animal's behaviour in the experiment might be affected by the incidental feeding contingency, if removal from the box was immediately followed by access to food.

113

CHAPTER 6.

ARITHMETIC PROGRESSIVE-INTERVAL

SCHEDULES OF REINFORCEMENT.

The experiments to be reported in this chapter were concerned with performance under arithmetic PI schedules of reinforcement. In these schedules each interval was longer than the preceding interval by a constant duration, and the duration of the first interval was equal to that of the constant increment⁽¹⁾. Thus, in arithmetic PI 60 sec, for example, the initial interval was 60 sec and the subsequent intervals 120 sec, 180 sec, 240 sec, and so on. The intervals were always timed "by the clock".

(1) The latter specification is not, of course, a necessary characteristic of arithmetic series. In some of Findley's (1958) experiments the initial interval and the increment were of different durations.

EXPERIMENT 1

Arithmetic PI 15 sec.

Subjects

Four male hooded rats, 200 days old at the start of the experiment, served as subjects. They were experimentally naive and their average deprivation weight was approximately 240 gm.

Procedure

t r a i n i n g: The animals were trained in two consecutive daily sessions. First, they were trained to approach the dipper; this was followed by the shaping of lever-press responses. The session terminated after approximately 40 lever responses were reinforced. In the second session 70 reinforcements were given on crf.

experiment: Arithmetic PI 15 sec was in effect the next day. 23 intervals were included in each session so that the total duration of a session was 69 minutes plus a maximum of 1 minute allowed for the next reinforcement. Thus, the reinforcement which became available at the onset of the 24th interval occurred if the animal made a response in the final minute of the session. In practice these reinforcements were always obtained.

33 daily experimental sessions were run in blocks of 5 sessions separated by week-ends; the first block of 5 sessions included the 2 training days. Results and discussion.

The gradual development of stable behaviour is illustrated by sample cumulative records of one animal, shown in Figure 20. The record of the 1st experimental session exhibited a course grain and was marked by irregularly spaced pauses. For example, the onset of the third interval coincided with the early part of such a pause and consequently the third and fourth reinforcements were closer in time than were the second and third reinforcements. The local rates of responding were variable and the post reinforcement pauses were very brief. By the 5th session, however, there were indications of scalloping and the coarseness of the grain, though still evident, was reduced. These changes continued in the subsequent sessions and the cumulative record obtained in the 12th day showed clear post-reinforcement In this record a tendency can be seen for pauses. the post-reinforcement pauses to become longer in the course of the progression of the schedule. Terminal rates of responding were rarely interrupted, and, once reached, continued until the next reinforcement. At this stage the number of responses emitted per interval increased with increases in the durations of the intervals.

By about the 22nd session the behaviour of all subjects became stable and no further changes were observable from session to session. This stable behaviour is shown in complete cumulative records of two subjects obtained dn the final day of the Figure 20 Cumulative records of one animal's responding in the 1st (upper record), 5th (middle record), and 12th (lower record) sessions of the experiment on arithmetic PI 15 sec.



experiment (Figures 21 and 22). It can be seen that in each inter-reinforcement interval well defined scallops occurred with prolonged postreinforceemnt pauses. Further, there was a tendency for these pauses to increase as the intervals progressed. It is interesting to note that during the first two or three intervals of a session the animals paused only briefly after reinforcement (figure 21), and that this is also typical of FI performance (cf Azrin and Holz, 1961). In some sessions, however, this phenomenon was not seen (Figure 22). A further characteristic of FI performance also observed in the present case was that occasionally the animal paused throughout an interval and reinforcement occurred after a single response. Examples of this, for FI, were given in Figure 7; similar examples from arithmetic PI performance can be seen in segment 2 of Figure 21 and segment 1 of Figure 22. These pauses were infrequent and no systematic explanation could be formed for their occurrence.

Inspection of Figures 21 and 22 also reveals that, once stable behaviour was established, the number of responses emitted per interval remained fairly constant throughout a session. This fact is further shown in Figures 23 and 24 where, for two animals, the number of responses emitted in successive intervals of the final session was plotted. This number increased in the first two or three intervals and



Figure 21 Complete cumulative record of one animal under arithmetic PI 15 sec in the final session of the experiment. The segments are numbered in the order of their occurrence.



Figure 22 Complete cumulative record of one animal under arithmetic PI 15 sec. The segments are numbered in temporal order.



Figure 23 Number of responses emitted by one animal in successive intervals of arithmetic PI 15 sec, in the final session of the experiment.



Figure 24 Number of responses emitted by one animal in successive intervals of arithmetic PI 15 sec, in the final session of the experiment.

thereafter remained more or less the same. The overall variability in responding is shown in Figure 25. This gives, for each of the four amimals and over the last five sessions, the mean and the standard deviation of the number of responses per interval. The variability in the present data was similar to that observed in FI performance (cf Figure 10). Of course, a direct comparison with any one FI schedule can not be made since there is no basis on which a particular FI can be selected for such a comparison.

The positive relationship between the durations of the intervals and that of the post-reinforcement pauses, seen by inspection of the cumulative records, is further illustrated in Figures 26 and 27. Although the pauses increased as a function of the durations of the intervals, there was also an increase in the difference between the two; that is, the increase in the post-reinforcement pauses was slower than that of This was somewhat similar to the the intervals. relationship observed between the interval specified by an FI schedule and the duration of the postreinforcement pause under that schedule (Figure 6). For the purpose of the present analysis the postreinforcement pauses were timed to the first response after reinforcement. As it was pointed out in previous discussion this method neglects the possibility that the pause may continue beyond an isolated response. Inspection of the cumulative records revealed, however, that such single responses



Figure 25 The mean and the standard deviation of the number of responses emitted per interval of arithmetic PI 15 sec. Data, shown separately for each animal, were calculated from the results of the last five sessions.



Figure 26 The mean durations of the post-reinforcement pauses in each interval of arithmetic PI 15 sec. Data, from a single animal, were calculated from the results of the final 5 sessions.



Figure 27 The mean durations of the post-reinforcement pauses in each interval of arithmetic PI 15 sec. Data, from a single animal, were calculated from the results of the final 5 sessions.

occurred rarely in the course of responding under arithmetic PI and since the method is the most stringent it was preferred.

The results of the present experiment indicated that rats can adjust to the changing temporal contingencies of the arithmetic PI schedule. The pattern of responding in any one interval was similar to the pattern which might be predicted under an FI schedule which specifies that interval. These findings were extended in the following experiments.

Summary.

Four male hooded rats responded under arithmetic PI 15 sec schedule of reinforcement. Somewhat irregular behaviour in early sessions gradually gave way to well defined scallops in later sessions. After the behaviour became stable the number of responses emitted in each interval of the schedule was constant, though the durations of the post-reinforcement pauses increased as a positive function of the durations of the intervals.

EXPERIMENT 2

Extended sessions on arithmetic PI 15 sec.

The sessions of the previous experiment were limited to 70 minutes and during these sessions no indications of change in the overall trends were observed. The present experiment was carried out to see what happens to behaviour in prolonged sessions. Subjects.

Two hooded rats from the previous experiment served as subjects.

Procedure.

In the course of two weeks after the end of Experiment 1 the feeding times of the animals were gradually changed from 2 p.m. and 4 p.m. to 8 p.m., since it was intended to run a 12-hour long session starting at 9 a.m. This was to minimise the possible effect of the feeding cycle on the experiment.

The present experiment was brief; it consisted of a single session⁽²⁾, for each animal, **which** last**en** approximately 12 hours. All other conditions and the schedule of reinforcement (arithmetic PI 15 sec) were the same as in Experiment 1.

Results and discussion.

The middle portion of the cumulative record obtained from one animal is shown in Figure 28 and the entire cumulative record of the second animal is contained in the Supplementary Volume to this theseis. Both the time and the response axes of the latter record were expanded in order to provide more detail⁽³⁾.

(2) At the time the conditions in the laboratory did not permit running such long sessions without interference by other experiments in progress. Time had to be found when the other investigations were suspended. At present a study is improgress in which the feeding cycle is 36 hours and daily sessions, 10 hours.

(3) Unfortunately on the morning of this experiment the tape-punch unit broke down. The above measure was taken in an attempt to compensate for this loss.

Figure 28 Middle portion of a cumulative record obtained in a single extended session of 12 hours under arithmetic PI 15 sec. The animal had no prior exposure to intervals of this length.



The cumulative records show that the scalloped pattern of responding continued throughout the 12-hour long session. In the long intervals which occurred towards the latter part of a session there were large number of responses but such response-runs were nevertheless preceded by long post-reinforcement pauses (e.g. Supplement pp. 18, 22, 26, 30, 34). In some intervals only a few responses occurred and occasionally reinforcement followed a single response. On only one occasion such a response, and therefore the occurrence of reinforcement, was delayed considerably beyond the onset of the new interval (Supplement pp. 16/17). On other occasions very long post-reinforcement pauses were followed by a relatively brief acceleration in the response rate, followed by reinforcement (e.g. Supplement pp. 19, 25, 27, 46). The overall maintenance of the pattern of responding and especially the latter patterns of behaviour are particularly remarkable in view of the fact that never in their experimental history had the animals been exposed to the long intervals of the present study. Their ability to adjust to the temporal requirements of approximately the last 11 hours of the session can only be attributed to previous experience in relatively short sessions of arithmetic PI 15 sec.

These findings suggest that experience under PI schedules may result in rapid and accurate behavioural adjustment to the temporal conditions of different and subsequently presented schedules of reinforcement. This possibility was further explored in an experiment to be described later (Experiment 7).

130

Summary.

Two subjects of the Experiment 1 were each exposed to a single 12-hour long session. The results showed that scalloped pattern of responses in every interval continued throughout the session. Although a relatively large number of responses was occasionally emitted in an interval, successive increases were maintained in the durations of postreinforcement pauses as a function of the progression of the schedule.

EXPERIMENT 3

Arithmetic PI 30 sec.

In this experiment the behavioural effects of arithmetic PI 30 sec schedule of reinforcement were investigated.

Subjects

Four male hooded rats served as subjects. They were approximately 150 days old and experimentally naive at the beginning of the study. Their deprivation weights were about 180 gm.

Procedure

t r a i n i n g: The animals were first trained to approach the dipper; the lever-press responses were then shaped and this was followed by approximately 50 reinforcements on crf. 75 further reinforcements occurred on crf on the second day of training.

experiment: Arithmetic PI 30 sec schedule of reinforcement was introduced the next day. The duration of an experimental session was slightly longer than 60 minutes; the first 60 minutes consisted of 15 intervals of the schedule and brief period was allowed for reinforcement at the end of the 15th interval.

A total of 35 daily sessions were run, including the 2 training sessions, in blocks of 5 days separated by week-ends. Further, the experiment was continued for 40 additional sessions with one of the animals whose behaviour was unusual. Results and discussion.

Complete cumulative records of one animal in the 1st and the 14th sessions are shown in Figure 29, in order to illustrate the gradual development of behaviour. The overall picture was similar to that seen in Experiment 1; in the 1st experimental session the record had a course grain and the animal paused only briefly after reinforcement. In the course of subsequent sessions responding became smooth and well defined post-reinforcement pauses occurred. The gradual increase of these pauses in the course of a session was evident by the 14th session. Although similar behaviour emerged in three of the subjects, the fourth animal's responding was remarkably different. The results obtained from the three subjects will he presented first.

Figure 29 Complete cumulative records of responding in the 1st and the 14th sessions under arithmetic PI 30 sec.

(1st session: upper record; 14th session: lower record).


Complete cumulative records of the last 5 sessions are shown, for two subjects, in Figures 30 and 31; the performance of the third subject was in all respects similar to those presented here. Once the behaviour became stable, the number of responses emitted per interval remained, given a certain amount of variability, stable in all sessions. The response curves tended to be somewhat more "grainy" towards the end of a session. The few occasions, when the number of responses in an interval was considerably greater than usual, tended to occur in later intervals of the schedule. This can be attributed to the fact that once a stable rate was reached responding continued until the next reinforcement. Consequently, given that a response-run started, more responses would be emitted in a long interval than in a shorter interval.

The post-reinforcement pauses were increasingly prolonged in successive intervals of the schedule. Although this trend can be observed in the cumulative records, it is more clearly demonstrated in Figure 32 in which the durations of the successive pauses by the third animal, in the final session of the experiment. were plotted. In the present case, as in Experiment 1, the pauses were timed to the first response after reinforcement.

The behaviour of the fourth animal used in this experiment was remarkably different from that of the other three. This animal responded at a fairly stable rate Figure 30 Complete cumulative records of responding by one animal in the last 5 sessions under arithmetic PI 30 sec. The pen re-set to baseline at reinforcement.

(The first (uppermost) record differs from the others due to a fault in the cumulative recorder).



Figure 31 Complete cumulative records of responding by one animal in the last 5 sessions under arithmetic PI 30 sec. The pen re-set to baseline at reinforcement. The vertical arrow on the top record also indicates reinforcement. In that interval only two responses occurred, one early in the interval and the second appreciably long after the next reinforcement was set-up.

136

man M M MMMMM $-M = 40^{n \text{ s/min}}$ MAAAAA A MAAAAA



Figure 32 Durations of the post-reinforcement pauses as a function of successive intervals of arithmetic PI 30 sec. Data are from one animal in the final session of the experiment.

The straight line shows the progression of the intervals of the schedule.

throughout the 35 sessions of the experiment and no discernible change of any kind occurred in its behaviour. The cumulative records of the first and last sessions were almost identical (Figure 330). typified by a course grain, a steady rate of responding, and very brief post-reinforcement pauses. After the 35 sessions the experiment was continued with this animal and a higher value schedule, namely, arithmetic PI 60sec was imposed. The duration of daily sessions was kept approximately as before so that 11 intervals of the schedule were included in a 60-minute session. Towards the end of 20 sessions under this schedule post-reinforcement pauses of appreciable duration emerged, but these were confined to earlier intervals. The overall response rate declined and responding was interrupted by irregular pauses. The complete cumulative record of the final session under arithmetic PI 60 sec is shown in Figure 33b. After 20 sessions the value of the schedule was increased again and arithmetic PI 90 sec was imposed. 9 intervals were included in each 67.5-minute session and 20 further sessions were run. Again, no appreciable change occurred in behaviour, apart from the fact that the post-reinforcement pauses in the early intervals of the schedule became somewhat longer than they were under the previous schedule. Figure 33balso gives the complete cumulative record of the final session of the experiment.

It has not been possible to find an explanation for this highly unusual behaviour ; indeed it remains unique amongst the results obtained from numerous studies of a variety of PI schedudes. There was no

138

Figure 33a Unusual behaviour by one animal under arithmetic PI 30 sec. Cumulative records of responding in the first (upper record) and the last (lower record) sessions of the experiment are shown.



Figure 33b Unusual behaviour by one animal in the final sessions under arithmetic PI 60 sec and 90 sec. This was the same animal whose performance on PI 30 sec was shown in Figure 33a.

(Arithmetic PI 60 sec: upper record; arithmetic PI 90 sec: lower record).



observable difference between this rat and the others in the laboratory; the animal was kept for approximately 18 months and in a subsequent autopsy no unusual features were seen.

The results obtained from the other three rats confirmed the findings of Experiment 1. It appears that behaviour can adjust, in general, to the changing temporal requirements of the arithmetic PI schedules of different values. Further support was sought for this conclusion in the next experiment. Summary.

Four rats were exposed, in 33 daily sessions, to arithmetic PI 30 sec schedule of reinforcement. The behaviour of three subjects adjusted to the temporal conditions of the schedules, viz. the number of responses per interval remained fairly constant and the post-reinforcement pauses increased in successive intervals.

The behaviour of one of the subjects exhibited unusual characteristics and was explored further; no explanation could be found, however, for the difference.

EXPERIMENT 4.

Arithmetic PI 60 sec and 90 sec.

This experiment investigated the behavioural effects of two further arithmetic PI schedules with the values of 60 seconds and 90 seconds.

Subjects.

Four male hooded rats were used as subjects. They were approximately 120 days old and naive at the start of the experiment. The average deprivation weight was 200 gm.

Procedure

t r a i n i n g: Dipper-approach and leverpress responses were shaped and approximately 50 consecutive responses were reinforced in the first session. In the second training session crf was in effect and 75 reinforcements occurred.

e x p e r i m e n t: Two rats were placed under arithmetic PI 60 sec and two rats, under arithmetic PI 90 sec. For the former schedule a session lasted 66 minutes and included 11 intervals; the sessions of the latter schedule were 67.5 minutes and included 9 intervals. In the last 10 days of the experiment the sessions under arithmetic PI 60 sec were extended for one animal to include 23 intervals; these sessions were 276 minutes. In all cases each session was extended slightly beyond the figures given since a brief period was allowed for the final reinforcement.

30 daily sessions were run in each case, including the two training sessions. Blocks of 5 consecutive daily sessions were separated by weekends. Results and discussion.

The gradual development of stable behaviour under both of the schedules was similar to that observed in the previous experiments and will not be described in detail. In general, the early behaviour was somewhat irregular and the cumulative records of the first few sessions displayed a co**d** rse grain. As the experiment proceeded relatively long post-reinforcement pauses emerged and the terminal response curves became relatively smooth.

In Figure 34 complete cumulative records obtained from one animal under arithmetic PI 60 sec, in the final 5 sessions, are shown. It will be seen that the number of responses emitted per interval was fairly constant and there was a tendency for successive increases to occur in the durations of the post-reinforcement pauses. A similar pattern was observed in the behaviour of the second animal. This animal had been exposed to extended sessions in the final 10 days of the experiment, and the results obtained under these conditions will be presented next. The number of responses emitted per interval was constant; Figure 35 gives the mean number of responses in each interval, calculated over the last 7 sessions. It will be seen that the present animal emitted fewer responses than the former subject. This is unlikely, however, to be related to the fact that the sessions were longer since similar inter-subject differences were seen in previous experiments where the sessions were of equal duration for all subjects (cf Figure 25). Figure 36

Figure 34 Complete cumulative records of one rat under arithmetic PI 60 in the final 5 sessions of the experiment. The pen reset to baseline at reinforcement.





Figure 35 Mean number of responses emitted by one animal under arithmetic PI 60 sec. Data were calculated from the results of the final 7 sessions.

shows the mean durations of the post-reinforcement pauses in the same 7 sessions. The pauses increased gradually, but this increase was considerably slower than the increase in the durations of the intervals. A further analysis was carried out on the present data: the IRT's were pooled, interval by interval, over the final 7 sessions and the relative frequencies were estimated in 1-second categories up to 20 seconds and thereafter in 10-second categories. The postreinforcement pauses were excluded from this analysis. The results thus obtained demonstrated, in a different way, the adjustment of behaviour to the temporal requirements of the schedule (Figure 37). In all the intervals, except the first, the most frequent IRT's were 1-2 seconds; 0-1 second IRT's were slightly more frequent in the first interval. The change in the distributions consisted of a marked tendency for longer IRT's to emerge from interval to interval. It is known from the earlier evidence that such long IRT's are rarely observed in the course of terminal responding. Thus it appears that the occurrence of long IRT's represented, in general, an extension of the curvature between the first response after reinforcement and the point when a steady response rate was achieved. This conclusion was supported by the results obtained by estimating the mean quarter-life of each interval over the final 7 sessions (Figure 38). The progression of the intervals of the schedule differed considerably less from the progression of the quarterlives than it did from the progression of the post-



Figure 36 Mean durations of post-reinforcement pauses in successive intervals under arithmetic PI 60 sec. Dotted line shows the durations of post-reinforcement pauses up to the second response after reinforcement. The straight line indicates the progression of the intervals in the schedule. The first pause was timed from the start of a session. Data were from the performance of one animal in the final 7 sessions of the experiment.



Figure 37 Relative frequency distributions of IRT's in alternate intervals of arithmetic PI 60 sec. 1-second categories are shown up to 20 seconds and thereafter 10-second categories. Data were obtained by pooling, interval by interval, the results from one animal in the final 7 sessions of the experiment. The post-reinforcement pauses were excluded.



Figure 38 Mean quarter-life of each interval under arithmetic PI 60 sec. Data were estimated over the last 7 sessions, from the results of one animal. The straight line shows the progression of the intervals. reinforcement pauses. In other words the longer an interval the greater was the difference between it and <u>either</u> the quarter-life <u>or</u> the post-reinforcement pause in that interval. This difference increased more sharply for the post-reinforcement pauses, however, than it did for the quarter-lives.

Under arithmetic PI 90 sec the general characteristics of responding were similar to those observed under the other arithmetic PI schedules. Complete cumulative records obtained from one animal in the last 5 sessions are shown in Figure 39. The number of responses emitted per interval remained fairly constant and the post-reinforcement pauses were prolonged successively. It will be seen that under this schedule, as well as under arithmetic PI 60 sec, the response curves of the last few intervals were somewhat more "grainy" than those of the earlier intervals. Since the course grain of a cumulative record is often seen in the early stages of an experiment it may be the case that in further sessions responding might have become more smooth. This suggestion is supported by the fact that the courseness of the records occurred in the longer intervals; in the case of FI schedules, for example, the longer the interval the longer is the training required to reach final stability. At present, however, there is no direct evidence from PI schedules bearing on this point.

150

Figure 39 Complete cumulative records obtained from one animal in the final 5 sessions under arithmetic PI 90 sec. The pen reset to baseline at reinforcement.



The overall results of the present experiment demonstrated further the ability of rats to adjust to the changing temporal conditions of arithmetic PI schedules. It appears that this ability is not confined to any one value of the schedule and that it is observable when the increments are as long as 90 seconds.

Summary.

Four rats responded under arithmetic PI schedules of reinforcement; two under arithmetic PI 60 sec, and two under arithmetic PI 90 sec. In all cases more or less the same number of responses were emitted in each interval of a session and as the intervals increased the post-reinforcement pauses became longer.

GENERAL DISCUSSION

The results of the experiments reported in this chapter demonstrate, in general, that behaviour adjusts to the changing temporal conditions of the arithmetic PI schedules. In a sense, however, it may be considered that these schedules are basically similar to FI schedules. A characteristic of arithmetic progression is that successive increments become proportionally smaller; in the schedules used here, for example, the first increment was 100% of the preceding interval but the next increment was only 50% of the interval which preceded it, and so on. Thus the increments declined at a fast rate at first

and then more gradually (Figure 40). Consequently in the later intervals of arithmetic PI the increments were proportionally small and in this sense the schedule gradually approximated to a FI schedule. In fact there was some indication in the results of the above experiments that this characteristic of the arithmetic PI schedules was reflected in the pattern of responding. Occasionally the post-reinforcement pauses tended to be of similar duration in blocks of 3-5 intervals of the schedule and increased from one such block to another. Concomitantly the number of responses emitted in each interval within such a block gradually increased; it then declined sharply in the first interval of the next block. This pattern may be seen in some of the cumulative records presented in the preceding pages; selected examples are given in Figure 41. These examples were chosen for the purpose of illustration and they are not representative of PI performance in general. The pattern was observed fairly often but not consistently in any one animal. In some animals only a slight tendency of this type was discernible. It seemed, nevertheless, that this evidence supported to some extent the possibility that an arithmetic PI schedule was, in effect, like a multiple FI In other words, the intervals in a block schedule. might affect responding as intervals of an FI schedule, and such blocks in a session, as FI components of a multiple schedule. This consideration gave rise to the question of whether behavioural adjustment would occur under a PI schedule in which

the successive increments were kept <u>proportionally</u> constant. The experiments described in the next chapter provide evidence in relation to this question.



Figure 40 Diagram to show the decline in the proportional size of the increments in arithmetic progression. The proportional of the increments are large at first and decline rapidly; with further progression both the proportions and the rate of the decline become smaller. Figure 41 Selected cumulative record segments to illustrate the block by block adjustment of responding under arithmetic PI 30 sec (upper two segments) and arithmetic PI 60 sec (lower segment). The pen reset to baseline at reinforcement.

100 Response MILIAA 5 Minutes MLML

CHAPTER 7.

GEOMETRIC PROGRESSIVE-INTERVAL SCHEDULE OF REINFORCEMENT.

This chapter is concerned with the effects on behaviour of geometric PI schedules. The first two experiments to be reported were carried out in order to obtain evidence on the characteristics of responding under these schedules; in the third and final experiment the effect of prior experience with these schedules on DRL performance was investigated.

In geometric PI schedules each increment was a constant proportion of the preceding interval; thus as the intervals became longer the absolute durations of the increments increased. In geometric PI 20% (60 sec)⁽¹⁾, for example, the initial interval

(1) This notation has the advantage of clarity but it is cumbersome and alternatives may be more convenient, e.g. GPI 20 (60). In fact the initial intervals of att the schedules used here were 60 seconds and hence the statement of the first interval in brackets is on occasion **e**mitted. was 60 seconds and each increment was 20% of the preceding interval. Thus successive intervals of this schedule were 60 sec, 72 sec, 86.4 sec, and so on.

EXPERIMENT 5.

Geometric PI 20% (60 sec).

Subjects.

Four male albino rats, approximately 140 days old at the start of the experiment, served as subjects. The average deprivation weights of the animals were about 240 gm and they were experimentally naive. Procedure.

t r a i n i n g: Only one training session was run. The animals were trained to approach the dipper and then lever-press responses were shaped. This was followed by 100 reinforcements on crf.

experiment: Geometric PI 20% (60 sec) was imposed the next day. A session consisted of 16 intervals and lasted 86.5 minutes plus a brief period for the occurrence of the final reinforcement. 30 daily sessions were run, including the training day, in blocks of 5 consecutive sessions separated by week-ends. The duration of the last 10 sessions was extended to 5 hours 22 minutes for one animal, to include 23 intervals. Results and discussion.

The development of behaviour followed a course somewhat similar to that seen under arithmetic PI schedules. Complete cumulative records of one animal in the 1st and the 9th sessions are given in It will be seen that in the 1st Figure 42. session responding was erratic; it was interrupted by frequent pauses and there was no sign of orderly post-reinforcement pauses. A reinforced response was often preceded by a relatively long pause. By the 9th day, however, the behaviour became more regular; even at this stage the number of responses per interval was remarkably constant although the post-reinforcement pauses were brief, notably in the In the latter earlier intervals of the session. intervals the pauses were appreciably long and thus signs of a tendency could be observed for these pauses to become longer as the session progressed.

Figure 42 shows the complete cumulative records of all 4 subjects in the final session of the experiment. In all cases a relatively constant number of responses were emitted in each interval and the variability of this number was less than that observed under arithmetic PI schedules.

It will be seen in the cumulative records (Figure 42) that the post-reinforcement pauses became longer in the course of the progression of the schedule.

Figure 42 Complete cumulative records of one animal in the 1st and the 9th sessions under geometric PI 20% (60 sec). The pen reset to baseline at reinforcement.


Figure 43 Complete cumulative records of four animals in the final session under geometric PI 20% (60 sec). The bottom record continued for 7 further intervals (not shown) since this subject was exposed to longer sessions than the other three. The pen reset to baseline at reinforcement.

(The motor of the cumulative recorder which produced the second record from the top had to be replaced - consequently the time base of this record is slightly different from the others).

In the top record the penultimate reinforcement occurred after a single response in that interval. Since the pen was already on the baseline the record does not show this reinforcement.



Figure 44 shows the same relationship, in terms of mean quarter-life per interval, over the last 5 sessions. In general the durations of the quarterlives increased as a function of the increase in the durations of the intervals. The difference between the two, however, became greater towards the latter part of a session. This phenomenon was also observed under arithmetic PI schedules (cf. Figure 38) but to a greater extent; that is, the proportion of an interval occupied by the quarter-life declined more slowly in the present experiment than it did under an arithmetic PI schedule.

The behaviour of the animal exposed to extended sessions was, in general, similar to that described The results obtained from this subject in above. the final 7 sessions are presented, in terms of mean number of responses per interval and mean durations of post-reinforcement pauses, in Figures 45 and 46 respectively. Figure 47 shows the relative frequency distributions of IRT's, pooled interval by interval, over the 7 sessions; the post-reinforcement pauses were excluded from this calculation. In the present case, unlike the IRT distributions obtained under arithmetic PI 60 sec (Figure 37), the overall characteristics of the distributions changed as the schedule progressed. By the 13th interval there was a shift in the modal frequency from 1-2 second category to 2-3 second category; the very short



Figure 44 Mean quarter-life per interval, over the last 5 sessions, under geometric PI 20% (60 sec). The data are from a single subject.

The smooth curve shows the progression of the intervals of the schedule.



Figure 45 Mean number of responses emitted by one subject in each interval of geometric PI 20% (60 sec). The means were calculated over the final 7 sessions. Data were from a single subject.



Figure 46 Mean durations of post-reinforcement pauses in successive intervals of geometric PI 20% (60 sec). The dotted line shows the pauses timed to the second response after reinforcement and the smooth curve, the progression of the intervals of the schedule. The first pause was timed from the start of a session. Data were from one subject.



Figure 47 Relative frequency distributions of IRT's in each interval of geometric PI 20% (60 sec). The IRT's are shown in 1-second categories up to 20 seconds and thereafter in 10-second categories. The data were obtained by pooling, interval by interval, the results from one subject in the final 7 sessions. The post-reinforcement pauses were excluded.

IRT's of 0-1 second duration, although frequent in the earlier intervals, almost disappeared from the 15th interval onwards. The relative frequency of the long IRT's, exceeding 20 seconds, increased gradually, and in the last two intervals the distribution appeared to be almost flat. Of course, a flat distribution indicates equal probabilities, that is, random responding. This is not the case here, however, since the IRT's longer than 20 seconds were in 10-second categories and also in view of the fact that there were long post-reinforcement pauses in every interval, excluded from the present data. The gradual change observed in the present case represents the fact that terminal responding in the longer intervals consisted of brief response runs separated by pauses. In general it appeared that responding towards the end of such an interval involved cycles, in which sequences of short and long IRT's alternated; moreover, the sequences of short IRT's were longer (consisted of more components) than the sequences of long IRT's. It is necessary to carry out sequential analyses in order to observe in detail the characteristics of this type of responding and unfortunately such evidence is not. at present, available.

The overall results of this experiment indicated that responding adjusts to the changing temporal conditions of the geometric PI schedule is it does to those of arithmetic PI schedules. Moreover there was a tendency for even greater stability in responding in the present situation. The next experiment sought to extend these findings.

Summary.

Four albino rats responded under geometric PI 20% (60 sec) schedule of reinforcement. Responding adjusted to the temporal conditions of the schedule; the number of responses emitted per interval remained stable and the quarter-lives increased progressively.

EXPERIMENT 6.

Geometric PI 10%, 20% and 30% (60 sec).

In this experiment the behavioural effects of three different geometric PI schedules were studied on the same subjects, in prolonged daily sessions which lasted approximately 7 hours.

Subjects.

Four male hooded rats were used. They were approximately 200 days old and experimentally naive at the start of the study. Deprivation weights were about 220 gm.

Procedure.

t r a i n i n g: Training took place in a single session in which the animals were trained to approach the dipper and then their lever-press responses were shaped. The session continued under crf until 100 reinforcements occurred.

experiment: Three schedules, geometric PI 10% (60 sec), geometric PI 20% (60 sec), and geometric PI 30% (60 sec) were used in successive daily sessions; since the initial intervals were all 60 seconds the schedules will be identified by only the percentage figure. The first two sessions were 2-hours; geometric PI 10% was in effect in the first session and geometric PI 30% in the second. Subsequently the sessions were extended as follows: 7 hours 20 minutes under geometric PI 10%, to include 38 intervals; 7 hours 36 minutes under geometric PI 20% to include 25 intervals; and 7 hours 6 minutes under geometric PI 30% to include 18 intervals. The order of presentation of the schedules was balanced as follows: 10%, 20%, 30%, - 20%, 30%, 10%, - 30%, 10%, 20%; this order was repeated three times. Thus the total number of sessions was 30, including the training day.

Results.

The development of behaviour was similar to that seen in the previous experiment and will not be described in detail. By about the 14th session responding became relatively stable even though the schedule was different in successive days. Moreover, behaviour showed characteristics appropriate to the schedule in <u>operation as can be seen by comparison</u> of Figures 48, 49, and 50. These Figures give the complete cumulative records of one animal in the final three sessions, that is, the final records Figure 48 Complete cumulative record of performance in the final session under geometric PI 10% (60 sec). The pen reset to baseline at reinforcement.



Figure 49 Complete cumulative record of performance in the final session under geometric PI 20% (60 sec). The pen reset to baseline at reinforcement.



Figure 50 Complete cumulative records of performance in the final session under geometric PI 30% (60 sec). The pen reset to baseline at reinforcement. (The pen reset soon after the llth reinforcement, as a result of a technical fault).



obtained of performance under each schedule. The number of responses emitted per interval was fairly stable under all the conditions, even in the very long intervals towards the end of a session. The pattern of responses was clearly scalloped in about the first 15 intervals and thereafter it was somewhat more variable. Since in later intervals the pesponses were distributed over longer periods, the local rates of responding which preceded reinforcements were low and on occasion a fairly long pause preceded a reinforced response. The post-reinforcement pauses increased gradually in the course of a session as did the quarter lives (Figure 51). Figure 52 shows the number of responses emitted by one animal in each interval of the three schedules in the final three sessions.

The present results revealed once again, the characteristics of behavioural adjustment seen in the previous experiments. Even in the prolonged daily sessions of this study the temporal orientation of the behaviour with respect to the changing requirements of the schedules was evident. The stability of responding was remarkable in view of the fact that in geometric PI schedules the increase in the absolute durations of the successive intervals was large. In the three schedules, for example, the initial interval of 60 seconds was in striking contrast to the final intervals of 37 minutes 10 seconds, 77 minutes 25 seconds and 66 minutes 14 seconds under geometric PI 10%, 20% and 30% respectively. A further point

Figure 51 The quarter-lives in the first 10 intervals (left panel) and the last 5 intervals (right panel) under geometric PI 10%, 20% and 30% (60 sec). Data were from one subject in the final session under each schedule. Since the number of intervals was different under each schedule different durations separated the first 10 and the last 5 intervals of each schedule.



Figure 52 Number of responses emitted by one animal in each interval of geometric PI 10%, 20%, and 30% (60 sec). The smooth lines show the progression of the intervals of the schedules. Data were from the final session under each schedule.



of interest was the relatively rapid development of stable behaviour under the complex conditions of the experiment. This, and the earlier findings from the animals who were exposed, on a single occasion, to an extended session under arithmetic PI, suggested that experience with the changing temporal conditions might result in increased precision of performance on temporally defined schedules in general. The next experiemnt was an attempt to followwup this suggestion.

Summary.

Four hooded rats were exposed to three different geometric PI schedules in all of which the initial interval was 60 seconds and the increments were 10%. 20% and 30%. Under each schedule the animals responded appropriately, viz. the number of responses per interval remained stable and the durations of the postreinforcement pauses increased progressively.

EXPERIMENT 7.

DRL performance after training on geometric PI schedules.

This is the final experiment to be presented in this thesis. It is concerned with the effect of prior experience under geometric PI schedules on responding under a DRL schedule.

Subjects.

Two animals from the previous experiment served as subjects.

Procedure.

An interval of two weeks was allowed from the end of Experiment 6 and then the animals were placed under DRL 20 sec. 20 daily 1-hour sessions were run in blocks of 5 separated by week-ends.

Results.

The cumulative record of one animal's performance in the 3rd session is given in Figure 53. A remarkable accuracy of temporally spaced responding was evident even at this very early stage. Figure 54 shows the cumulative records obtained from each subject in the final session. It is clear that the performance indicated by these records was highly precise, and not typical of the species used in this experiment. This degree of accuracy in the temporal distribution of responses has been observed in higher mammals, for example in monkeys (cf Weiss, Laties, Siegel, and Goldstein, 1966), but not in rats. It appears that exposure to changing temporal conditions results in improved performance on DRL schedules, although such a general statement needs to be supported by further evidence. A finding by Staddon (1965) has a bearing on the present results. This investigator reported that the exposure of pigeons to several different values of DRL schedules resulted in improved temporal discrimination although extended exposure to the same schedule had no such effect. Moreover, the findings of the present study are somewhat reminiscent of the results obtained in studies concerned with learning

Figure 53 Cumulative record of one animal's performance in the third session under DRL 20 sec. The animal had prior experience under geometric PI 10%, 20% and 30%. A remarkable precision of responding on DRL is evident even at this early stage.

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Figure 54 Cumulative records of the performance of two animals on DRL 20 sec in the finat experimental session. The upper two segments are the records of one animal and the lower two, the records of the second **Animal**.

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sets (e.g. Harlow, 1958). The latter phenomenon consists of a marked improvement in performance on, usually, a choice or discrimination problem as a result of repeated prior exposures to problems of similar kind. The improved performance observed here was based on repeated exposures to a series of timeintervals. In a sense, however, the "problem" was different since DRL imposes a restrictive contingency upon responses which fall short of the temporal requirement of the schedule whereas no such restriction is involved in PI schedules.

Summary.

Two hooded rats previously trained under three different geometric PI schedules were exposed to DRL 20 sec. The temporal spacing of responses in the latter condition was remarkably accurate, above the usually observed DRL performance of rats.

CHAPTER 8.

CONCLUSION:

TEMPORAL ORIENTATION OF BEHAVIOUR.

It seems plain from the results of the experiments described in the preceding chapters that behaviour adjusts to changes in temporal conditions. This adjustment takes place when the change involves a sequential regularity, whether the regularity is based on the constancy of absolute differences in the intervals specified by a PI schedule, or on the constancy of proportional differences. There were indications in the present findings that responding is more stable in the latter case, that is, when the progression of the intervals is geometric; and it was suggested that in the case of arithmetic progression blocks of intervals may resemble different FI components in their effects on behaviour. If this is correct, prolonged training would reduce the

variability observed in responding on an arithmetic Such a prediction is based on the PI schedule. consideration that, given the above assumption, arithmetic PI schedules resemble multiple schedules and that on the latter type schedules behavioural stability is achieved over a relatively large number of sessions. Of course, it is possible to view all PI schedules as varieties of multiple FI schedules arranged so that, in a single session. each component consists of a single interval and It is not unlikely that under such occurs only once. a schedule, whatever the components, behavioural stability would be ultimately achieved.

In the present experiments stable behaviour developed very rapidly although it may be the case that a final steady-state was not reached. This is suggested by the marked grain of the response curves in the longer intervals but at present there is no direct evidence which bears on the point.

In fact there are a number of questions which arise from the present findings and for which no answers have been provided. In view of the problem of whether PI schedules may be considered as multiple schedules, for example, it appears pertinent to investigate the behavioural effects of a schedule which consists of different intervals arranged not in orderly progression but in mixed order. Of course, this is in effect a variable-interval (VI) schedule,

but the suggestion is that the order of intervals should be held constant in each session. Experimenters who work with VI schedules usually take precautions to ensure that the order of intervals is not repeated, on the assumption that such regularity would be reflected There is little detailed evidence at in behaviour. present, however, on what would be the characteristics of behaviour which reflected this regularity. Moreover. it may be the case that exposure to such a schedule may subsequently result in improved performance on other temporally based schedules, in the same way as exposure to geometric PI affected DRL performance. In the latter experiment the animals had prior experience with three different geometric PI schedules; it is not known whether such varied training is a necessary condition of the subsequent accuracy of performance on DRL. Indeed, although the results were clear, the experiment stands alone and has not yet been replicated.

124

The main point of interest for the present thesis, however, was in problems concerned with temporal discrimination. The basic distinction between the phenomena which are in general termed discrimination and "temporal discrimination" was discussed in Chapter 2. It was pointed out that, when the duration of an explicit stimulus is discriminated, this is similar in principle to the discrimination of that stimulus with reference to a dimension other than time, such as length, brightmess, colour, and the like. In general the term "discrimination" implies

the existence of stimuli to be discriminated; indeed, the term "stimulus control" is used by many authors in preference to "discrimination" (e.g. Terrace, 1966). It is by extension of this usage that temporal discrimination is said to occur when what is observed is a correlation between the temporal distribution of (i) responses and (ii) some other series of events, such as reinforcements. When these events are more or less uniformly spaced in time, that is, when a single interval occurs repetitively, it appears tenable to include the behavioural phenomenon amongst those termed discrimination. This becomes less feasible, however, when a similar correlation is based on successively different intervals; it then has to be stated that as many "discriminations" are observed as there are intervals in a progressively changing schedule. It is proposed, therefore, that the term "temporal discrimination" be reserved for those situations which involve the discrimination of an explicit stimulus on the basis of its duration; and that the correlation of the temporal distribution of responding with the specified distribution in time of reinforcements be described as temporal orientation of behaviour.

75

The proposal has implications beyond a mere revision of terms. It is the inclusion of temporal orientation of behaviour amongst phenomena of discrimination that leads to the postulation of stimuli on which such "discrimination" may be based. Most of the questions posed by investigators are concerned with the nature of these stimuli, with whether they are

overt, covert, response-produced, and so on. These questions involve the implicit assumption that such stimuli, whatever their nature, can in principle provide the basis of the temporal distribution of responses. Moreover the apparent plausibility of this assumption reflects the fact that current experimental literature is concerned almost entirely with the "discrimination" of a single, repeatedly presented The studies which have used more complex interval. schedules of reinforcement, such as multiple DRL and conjunctive FI DRL, differ only to the extent that the same organism is exposed to two or more repetitive intervals. The presentation of different intervals may alternate singly or in sequences, as in the cases of multiple and chain schedules, or may be superimposed one upon the other, as in the case of a conjunctive schedule. In all these cases it is the repeated occurrence of equal intervals which renders tenable explanations in terms of collateral behaviour, response chains, or internal stimuli. The control of responding by the temporal contingencies of the PI schedules demonstrates, however, that a repeated pattern of behaviour (or stimuli) between reinforced responses, whether collateral behaviour or chain of responses, cannot satisfactorily explain temporal orientation of behaviour. These behaviours may and do occur under some conditions, and when they do they may contribute to the accuracy of responding. But their occurrence is not a necessary condition of

temporal orientation of behaviour since the present evidence suggests that behavioural adjustment to temporal contingencies can be more complex than the discrimination of uniform durations. In experimental situations in which there are no explicit timecorrelated stimuli the organism does not discriminate time but its behaviour is oriented in relation to time. This distinction has the advantage of directing attention to the need for studying the conditions in which behaviour may become temporally oriented. Skinner (1938) pointed out that whenever regular temporal relations exist between experimental events, whether explicitly programmed or not, sooner or later behaviour will be affected by these relations. The present evidence indicates that temporal control may enter into the determination of the pattern of behaviour in an experiment not only when the regularity is absolute but also when it is proportional.

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188
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197

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