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OPERANT BEHAVIOUR : INTERACTIONS IN MULTI-OPERANT SCHEDULES

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SUMMARY

Much recent research on concurrent schedule performance has centred on the matching law as a description of the relation between reinforcement and behaviour. Herrnstein's (1961) experiment showed that relative response rates approximately equal relative reinforcement rates in concurrent variable-interval schedules when a changeover delay is employed. The body of research which has followed from this finding was reviewed in detail.

Matching was found to provide at least a good approximation to the relation between relative response and reinforcement rates when methods similar to Herrnstein's are employed. Experiments which varied from this standard were discussed, and their results used to try and establish some limits on matching. In particular, differences were noted in the results obtained when allocated time rather than response rate was used as a measure of behaviour. The data obtained from experiments where the parameter of reinforcement varied was other than rate were not well accounted for by matching. Some further issues discussed concerned the nature of matching and its relation to the concept of reinforcement relativity. In the last sections Herrnstein's (1970) equations for absolute response rates in concurrent, multiple and single variable-interval schedules were described and evaluated with extant data.

Experimental work was carried out in several areas where the generality of Herrnstein's equations has been questioned. The first of these concerned concurrent performances when the alternatives differ in the response form which is reinforced. In addition to bias toward one response, the animals' allocation of behaviour was less sensitive to changes in relative reinforcement rate than predicted by matching. This was confirmed in a second experiment, and, in addition, the degree of preference for one response over another was shown to be dependent upon the type of reinforcer used. The implications of this finding for the equations used to describe absolute response rates were considered.

The literature review also revealed that matching is circumscribed by the need to employ a changeover delay of sufficient length. An alternative contingency, the changeover ratio, was employed in several experiments. It was found that as the changeover ratio is increased, rate of switching between alternatives decreases, and therefore mean time between changeovers increases. When changeover ratios are used local response rate is faster in the alternative to which more time is allocated. In different experiments preference was directed by arranging different changeover ratios for the two directions of switching, making the size of one ratio contingent upon time allocated to the alternative, and arranging unequal rates of reinforcement. Observations of the way in which local response rate and local reinforcement rate varies with post-changeover time were used to interpret these findings. Matching was only found across a small range of changeover ratio sizes.

The third set of experiments considered multiple variable-interval schedule performance. Some recent research has suggested that behavioural contrast may be partly the result of behaviour generated by Pavlovian contingencies. Such behaviour clearly lies outside the purview of Herrnstein's account. In the first two experiments it was shown that contrast can be produced using rats when the stimuli are located on the manipulandum, but is critically dependent upon the discriminability of the stimuli. Contrast was also found when responses on a different manipulandum, remote from the stimuli, were reinforced. Local and overall contrast effects were interpreted as suggesting that Pavlovian contingencies are only important when the operant contingencies are not very powerful. The relation between reinforcement rate and the rate of other behaviour was investigated in a fifth experiment and the results used to interpret some previous findings.

The analysis of contrast data suggested that Herrnstein's equation for absolute response rates may be modified so as to account for local response rate patterns. Using fixed-interval performance as a model, the proposed equation proved to be successful. Possible extensions of this type of analysis were discussed. These and the other results were summarized briefly in a final chapter where the relations between local response rates, local response rate patterns and matching were considered.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university and to the best of my knowledge and belief contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Signed__

Jason M. White

20th February, 1979

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CHAPTER 1

INTRODUCTION

1.1. CONCURRENT SCHEDULES

Skinner's (1938) "The Behavior of Organisms" provided a basis for the development of a science aimed at the prediction and control of behaviour. While our understanding of behaviour has advanced considerably since that time, researchers continuing in the tradition begun by Skinner have retained many of his conceptions and methods. Indeed, this influence pervades not only the experimental analysis of behaviour, but much of modern experimental psychology.

Skinner clearly delineated operant from respondent conditioning, but showed particular interest in the former and described a methodology for its study. This is now well known, with its emphasis on discrete identifiable units of behaviour free to occur in time, and the effects of consequential events on the rate of occurrence of these behaviours. Another notable aspect of the experimental analysis of behaviour is the intensive study of small numbers of subjects.

Several definitions are basic to Skinner's system. A stimulus is defined as an environmental event which influences the occurrence of a particular response. Reinforcers are stimuli, the presentation of which increases the rate of the behaviour on which they are contingent. The class of responses which shows an orderly increase in rate with reinforcement is designated an operant.

These definitions are clearly interdependent and functional in nature. A reinforcer can only be identified by the effect it has on behaviour and the class of responses so affected must be observed by the experimenter to change in rate in an orderly way. Similarly, a stimulus is not simply something occurring in the environment, but is defined by its effect on behaviour.

The rules for the presentation of stimuli and reinforcers in an animal's environment are termed contingencies. For example, lever presses may only be reinforced with a food pellet in the presence of a noise of a certain intensity. More complex contingencies, particularly those in which reinforcement only intermittently follows a response, are denoted by the term schedules of reinforcement. Performance on many such schedules have been studied and categorised. Ferster and Skinner (1957) have provided definitions of a wide range of reinforcement schedules, and documented the characteristic response patterns generated by each.

Of particular interest here are concurrent schedules, which specify two or more alternative responses whose consequences are under the control of the experimenter. Ferster and Skinner (1957) defined concurrent operants as

> Two or more responses, of different topography at least with respect to locus, capable of being executed with little mutual interference at the same time or in rapid alternation, under the control of separate programming devices.
>
> (p.724)

Such a definition allows pairs of responses which can be performed simultaneously, but which are reinforced according to two different schedules. Catania (1966) has pointed out that this compatability may lead to concurrent superstitions, or accidental correlations between the occurrence of one response and reinforcement for another. While the intention may be to control each response by a different schedule of reinforcement, one or both responses may come partially under the control of both schedules, or one schedule may control both responses.

The former outcome can be illustrated by the results of an experiment by Ferster (1957). Chimpanzees were reinforced for presses on two keys (compatible responses) according to VI and FR schedules respectively. As a consequence of a number of simultaneous presses, the pattern of responding on each key differed notably from that usually obtained when the schedules are programmed separately. The latter outcome is exemplified by Sidman's (1958) concurrent reinforcement of chain-pulls on a VI schedule of food reinforcement and bar-presses on an avoidance schedule. The compatability of these two responses for the monkeys used in this experiment resulted in control of both by the avoidance schedule. Manipulation of the parameters of the reinforcement schedules in a second part of the experiment caused bar-pressing to come partially under the control of the VI schedule.

The joint control of responses by several schedules may be a valid area of research in its own right, but in order to study preference for different operants each must be controlled solely by its reinforcement schedule. While response incompatibility does not ensure independence of concurrent operants, as discussed below, it is a necessary condition. We will therefore not consider all concurrent operants falling within the bounds of the definition above, but only those which involve responses which cannot, or functionally fail to occur simultaneously.

Early work on concurrent schedules was of an exploratory nature, employing a variety of different simple reinforcement schedules in combination. Even with incompatible responses, the pattern of responding on each schedule often seemed to be determined partly by the rate at which reinforcement was delivered according to the other. In other instances the patterns of responding controlled by each schedule were very similar to those observed when the schedules were programmed separately. Ferster and Skinner (1957) provided examples of both types.

A second method for arranging concurrent operants was described by Findley (1958). Both operants are performed on the same manipulandum, while a response on a second manipulandum changes the schedule arranging reinforcements. Two principle advantages ensue from such an arrangement. Firstly, the response of changing from one alternative to the other is made explicit, and thus may be more easily studied as an operant in its own right. A corollary is that the time allocated to responding on each of the schedules may be more exactly measured. Secondly, any possibility of asymmetries in required force, size of manipulandum etc., is eliminated, reducing the possibility of any bias when we wish the operants to be topographically the same. The two different methods of arranging concurrent operants appear to be equivalent across a wide range of experimental conditions.

1.2. HERRNSTEIN'S (1961) EXPERIMENT

An experiment by Herrnstein (1961) established the importance of studying concurrent schedule performance as a means of quantifying the effects of reinforcement. This was the occasion of the first statement of what has come to be known as the matching law. In addition, a method was outlined for the prevention of concurrent superstitions: the changeover delay (COD). This has since been almost universally employed in studies of concurrent schedule performance. For these reasons, and because it serves as a model for a number of experiments to be discussed, Herrnstein's experiment will be described in detail.

Three pigeons were each exposed to daily sessions in a chamber containing two response keys (0.75 inch diameter circular perspex discs which could be operated by a force of 15 grams) and a retractable hopper filled with grain. Pecks on each key were reinforced according to independent VI schedules with 4 secs access to the grain. Thus, the pigeons were confronted with two alternatives involving the same response, reinforcer and schedule type. Values of the two VI schedules were varied across the different conditions of the experiment so that relative reinforcement rate for each alternative assumed a range of values, but total reinforcement rate was approximately constant.

Besides the distribution of reinforcements across the alternatives the other independent variable was the presence or absence of the COD. This arranged for a minimum time (in this case 1.5 secs) between a changeover and reinforcement. The first response following a switch from one manipulandum to the other started a 1.5 sec period during which any reinforcements which had been "set up" by the VI timer were delayed. Only responses following termination of the interval could be reinforced. This discouraged any tendency to switch after only a few responses. Although responses occurring during the COD period had no programmed consequences, they were still counted. In addition, VI timers were not interrupted by COD periods. Each operated continuously unless it had set up a reinforcement.

Each condition of the experiment yielded a value for the relative frequency of responses on one alternative and for the relative frequency of reinforcement for that alternative. Considering only conditions in which a COD was enforced, Herrnstein found that when these values were plotted against each other, a relation of approximate equality was revealed. This can be expressed by the equation

$$\frac{R_1}{R_1+R_2} = \frac{r_1}{r_1+r_2} \qquad (1.1)$$

where R_1 and R_2 are the numbers of responses made on each manipulandum, and r_1 and r_2 the respective numbers of reinforcements. Since rates in concurrent schedules are calculcated using total session time (i.e. time during which each response is available) as the denominator, response and reinforcement rates may be substituted for absolute numbers in the equation. This relation is the matching law.

Two principal effects of the COD were observed in this experiment. Firstly, relative rate of responding tended to fall between the relative reinforcement rate and indifference (i.e. equal amounts of responding to the two alternatives) when no COD was employed. That is, the organisms seemed less sensitive to the distribution of reinforcements across alternatives without the COD. As expected, the COD also reduced the rate of switching from one alternative to the other. Both these effects, and their relation to matching, will be discussed in the next chapter.

Herrnstein suggested that the basis of matching lay in a proportionality between response and reinforcement rates, expressed by the equation

$$R = kr \tag{1.2}$$

With two alternatives for which the value of k is the same, the derivation of Equation 1.1 is obvious. However, Herrnstein failed to find the support in the results of other experiments which his data gave it. He postulated that the reason for this was the absence of a COD in the experiments which provided contrary data. This remained unsubstantiated.

In summary, Herrnstein demonstrated that the relation between relative frequency of responding and relative frequency of reinforcement in concurrent schedules could be precisely and simply stated. It is important to note that this relation reflects a property of the subjects and not of the procedure used. With VI schedules reinforcement rate is only slightly influenced by response rate, given the minimum rate of responding usually observed. Thus there is no *a priori* reason to suppose that the relation expressed by Equation 1.1 will hold with pairs of concurrent VI schedules. Many types of relationships could have been obtained.

Herrnstein's research is clearly in the tradition begun by Skinner (1938). Quantitative laws were accepted by Skinner as the logical outcome of the development of his system. However, he has cautioned against premature use of mathematics, insisting rather that the important variables and relations among them be identified before equations are stated (e.g. Skinner, 1938). Herrnstein's experiment raised the possibility of being able to specify such relations with general quantitative laws, and provoked a considerable amount of research as a consequence. This body of research will be considered in the next chapter. Firstly, however, some other implications of this experiment will be considered.

1.3. CHOICE IN A BEHAVIOURAL ANALYSIS

Choice is a concept central to much of psychology. Subjects completing a personality test may be required to choose between several different answers to a question. Statements are made about their personality on the basis of such choices. In a perceptual experiment subjects may be asked to choose which of several different figures most resembles a standard. The essense of all such situations is that the organism is confronted with several different courses of action. When one of these is adopted the subject is said to have made a choice or decision.

There is considerable variation in the type of explanations of why one alternative is chosen over another. However, most rely on a variety of intervening variables or hypothetical constructs to explain how choices are made. For example, learning theorists use notions such as expectancy and value, while decision theorists discuss subjective utility and subjective probability. In each case the state or value of each intervening variable is inferred from the conditions surrounding the choice. These values are then used to predict which course of action will be adopted.

In such a context choice or decision making becomes a higher mental process. But concurrent schedule performance may also be said to exemplify choice since the experimenter confronts the organism with two or more possible responses. As in any choice situation the independent variables will include the actual responses required and the consequences for each alternative. An experimental analysis may then be concerned with the relation between frequency of choice of each of the alternatives and these independent variables, obviating the need for hypothetical constructs.

Herrnstein's (1961) experiment exemplifies this type of analysis and demonstrates the sort of orderly relations which may be derived. In this case the independent variable was the rate at which reinforcement followed responding on each alternative, and relative frequency of responding was used as a measure of response or choice strength. As will be shown in the next chapter, the same type of analysis may be applied when considering the effects of other parameters of reinforcement.

As Herrnstein (1970) has noted, choice seems to be nothing more than behaviour set in the context of other behaviour. A corollary of this view is that simple execution of a response, with no explicit alternative available, can be considered as choice. There is always a context provided by those other responses in the organism's repertoire which it is able to emit. The identification of choice with behaviour will be pursued in the next chapter. It is clear, however, that a complete analysis of the variables influencing choice may proceed without the construction of a hypothetical description of the "decision-making process". This view is basic to an understanding of the implications of the research to be reviewed and reported here.

CHAPTER 2.

THE MATCHING LAW : A REVIEW

2.1. INTRODUCTION

A large body of research has followed from Herrnstein's (1961) original experiment. Much of this is concerned simply with extending the generality of matching. Experiments which fall within this category have tended to closely follow the model provided by Herrnstein, but with slight variations in procedure, subjects or some other variable. Most of the experiments described within the first three sections may be classed in this way.

However no scientific problem remains static, and the matching law is no exception. Contrary results inspired research that concentrated upon the particular variable which seemed responsible for the deviation from matching. For example, the COD has been found to be critically important, and research solely concerned with the effects of this procedural variable are discussed in Section 2.4, and again in Chapter 4.

Successes as well as contrary instances have led to research which deviates from Herrnstein's (1961) model. When it was found that matching was more general than the particular arrangement of the original experiment, attempts were made to extend its province by appropriate rearrangement and modification of the original equation. One such attempt is the subject matter of Chapter 5.

As a result of the constantly expanding body of research whose origins can be traced to Herrnstein's (1961) experiment, matching has largely become a framework for the study of schedule interactions and choice. Thus many experiments are not directly aimed at verifying matching but employ the equations to verify some other relation. However such experiments may still be employed as evidence for or against matching.

Many of the topics to be discussed here have been covered in a recent review of research on matching (de Villiers, 1977). Consequently, emphasis will be given to areas where a significant amount of research has been reported since the writing of de Villiers' review, or where the conclusions here differ from those of de Villiers. Where a topic is well covered by de Villiers, this fact will be acknowledged without repetition of the same material or arguments.

2.2. VERIFICATION OF HERRNSTEIN'S (1961) RESULTS

The experiments of interest here have all dealt with the problem of the replicability of Herrnstein's (1961) data. In addition, all have provided strong support for the original matching relation. Most, of course, deviate in some aspect (procedure, subjects, etc.) from Herrnstein's original experiment. While this establishes some generality, all share in common the use of concurrent variable-interval schedules with symmetry of response and reinforcement types across the alternatives and, with one exception, the use of a COD. In each case relative reinforcement rate is one of the independent variables.

A review of such data demonstrates the solid empirical base for matching in its original form. Without such data matching could be regarded simply as an artifact of the particular configuration employed by Herrnstein (1961). Once such a base is established, however, we may proceed to consider the relative worth of evidence for and against matching.

The earliest research which provided a test of matching was a series of experiments done by Autor in 1960 as part of a doctoral dissertation. These experiments, reported by Autor (1968), were concerned with conditioned reinforcement, and used the concurrent-chains procedure. That is, each of the concurrently programmed schedules was a two-link chain.

Each pigeon was initially presented with two illuminated keys. Responses on each key were reinforced according to independent VI 1 min schedules (the initial links). Reinforcement consisted of entry into the terminal link associated with that key, and was signalled by a change in the stimulus on the key, and darkening of the other key. Food reinforcement could then be obtained by responding on the illuminated key. Once a single food reinforcement had been obtained, the initial links were reinstated. During terminal links the initial link VI timers were halted. The two terminal-link schedules were always of the same type. In different parts of Autor's experiment they were VI, VR or DRO schedules. For each terminal link schedule type the value of one schedule was constant while the value of the other was varied across the different conditions.

Autor found that the relative frequency of responses on one initial link approximately equalled the relative density of reinforcement in the associated terminal link. Density was calculated in two different ways for the VI and VR terminal-link conditions: as frequency or rate of reinforcement (the usual measure) and as probability of reinforcement (number of reinforcers divided by number of terminal-link responses). Since DRO schedules require a certain period of not responding for reinforcement, only the first of these measures could be used for conditions in which they were the terminal-link schedules. The amount of variation from matching did not appear to be affected by the dependent variable used.

Autor's results show matching between relative frequency of responding and relative frequency (or probability) of reinforcement signalled by the stimulus change which maintained that responding. The change from initial-link to terminal-link stimuli may be regarded as a conditioned reinforcer whose value is proportional to the frequency or probability of reinforcement that it signals. The relationship may then be considered a match between relative response rate and relative value of conditioned reinforcement. Expressing the relationship in this way makes the similarity to Herrnstein's (1961) result more obvious. The use of the term 'value' in regard to the matching law will be discussed in Section 2.7.

Reynolds (1963) also verified that the matching relation holds for conditioned reinforcement. In this experiment the initial links were two or three concurrently programmed VI 1.5 min schedules. Reinforcement for initial-link responding was access to terminal-links where food could be obtained according to FR20 schedules. However with probabilities which varied across the keys, a period of time-out (TO) was substituted for the FR20 schedule. (Both keys were darkened and all operations halted during TO periods.) The initial-links were reinstated after food had been obtained or the TO period had terminated. With both 2- and 3-key procedures, the relative frequency of key-pecking during initial links matched the relative frequency of terminal-link reinforcements.

Catania (1963a) performed an experiment which was similar to Herrnstein's (1961) in many respects, with almost the same results. He used the changeover-key procedure with pigeons reinforced according to concurrent VI schedules. With the changeover-key procedure the COD is timed from the switching response. For each subject relative response rate closely approximated relative reinforcement rate when a 2 sec COD was enforced, but with no COD there was considerable deviation from matching. Catania was principally interested in verifying an alternative to Equation 1.2 which will be discussed in Section 2.9.2.

An experiment by Stubbs and Pliskoff (1969) also employed the changeover-key procedure with a 2 sec COD. Again the subjects were pigeons and the reinforcer food. Results from the three subjects closely conformed to matching.

McSweeney (1975) used pigeons, but the reinforced response was treadle-pressing rather than key-pecking. The treadles were small metal plates which the pigeons pressed with their feet. A VI schedule arranged reinforcement for pressing on each treadle. In all but one condition response proportions closely approximated reinforcement proportions with no COD. When a 2 sec COD was introduced, the results from the exceptional condition more closely approximated matching.

Baum and Rachlin (1969) reinforced the responses of standing on one side of a chamber or the other. Reinforcements were arranged by two concurrent VI schedules with a 4.25 sec COD. Since there was no discrete response, the dependent variable was the time the subject spent on each side. They found that the time proportion closely approximated the reinforcement proportion if a coefficient which accounted for the birds bias to the right-hand side was added to Equation 1.1.

Several experiments by Baum have attempted to demonstrate the validity of the matching law under more "naturalistic" conditions. In the first of these (Baum, 1972), the subject, a pigeon, lived in the experimental chamber for 7 months, obtaining all its food by pecking on two keys. The reinforcers were delivered according to concurrent VI schedule pairs. Relative response rates closely matched relative reinforcement rates. In the second, Baum (1974b) used a flock of about 20 pigeons in a large enclosure. Again pecks on two keys were reinforced according to concurrent VI schedules. The keys were arranged so that only one bird could respond at any time. The results obtained from the group as a whole showed close approximation to matching.

The experiments described above have all used pigeons as subjects. One experiment which employed rats, and found good agreement with the matching law was by Norman and McSweeney (1978). Presses on each of two bars were reinforced with food according to concurrent VI schedules. The COD was set at 5 secs. With one VI schedule held constant while the other varied, matching of both time and response ratios to reinforcement ratios was closely approximated. (Equation 1.1 can be expressed in the algebraically equivalent form $R_1/R_2 = r_1/r_2$).

Three experiments have verified the matching law using human subjects. The first of these, Schroeder and Holland (1969), illustrates several interesting variations on the usual experimental procedure. Subjects were required to monitor a display of four dials, each of which had a pointer, and to press the appropriate switch when one of the pointers deflected. One VI timer controlled deflections for the two right-hand dials, the other for the two left-hand dials. Once reinforcement (a deflection) had been set up by a VI timer, it was randomly assigned to the upper or lower dial of the pair. Each of the two measured response classes comprised the large saccadic eye-movements between the two dials on that side, while changeovers were eye-movements from one side to the other. The COD was set at either 0, 1 or 2.5 secs, and the value of the two VI schedules was varied. Response proportions closely matched reinforcement proportions when the COD was 2.5 secs, with greater deviation at COD = 1 sec, while there was little resemblance to matching with no COD.

Baum (1975) similarly reinforced behaviour with unpredictable signals. In this case a response consisted of holding down one of two telegraph keys. One type of signal could be detected only when the right-hand key was depressed, the other only when the left-hand key was depressed. The signals were arranged according to a VI 30-sec schedule and were randomly assigned to be one or other signal type. The two probabilities of assignment were varied across the different conditions. Two other contingencies, punishment for letting go of a key and a 2-sec COD, prevented rapid alternation between the keys. The dependent variable was the total time for which each key was depressed. For two of the four subjects relative time approximately equalled relative reinforcement rate, while there was significant variation in the other two cases. However when the COD was increased to 10 secs, the behaviour of these two subjects more closely conformed to matching.

Bradshaw, Szabadi and Bevan (1976) used the changeover-key procedure with human subjects. Responses on one button were reinforced according to a concurrent VI VI schedule with points which could be exchanged for money. Presses on a second button were required for switching between schedules. One VI schedule was constant throughout, while the rate at which the other arranged reinforcements was varied across conditions. Although no COD was employed, for both subjects relative reinforcement rate approximately equalled relative response rate.

The experiments which have been reviewed here provide strong support for Herrnstein's original formulation of the matching law . They cover a wide range of experimental conditions within the limits specified at the beginning of this section. In particular, matching has been found with a variety of subjects, responses and reinforcers (both primary and conditioned), in group behaviour and when the subject lived in the experimental chamber. The experiments described here do not exhaust those which provide empirical support for matching, but many of the other experiments which could be cited varied reinforcement rate across only one or two values.

2.3 ASSESSMENT OF THE EMPIRICAL SUPPORT FOR MATCHING

Having established that matching can accurately describe behaviour generated in a wide variety of experimental conditions we may proceed to consider the relative strengths of the evidence for and against matching. Evidence which may be regarded as contradicting an equation such as 1.1 need not take the form of data which deviate considerably from the prediction of the equation. Such variation may result simply from poor experimental control. Rather, it is the demonstration that the deviations are of a systematic rather than random nature which is the most damaging. Thus, before we can assess the evidence for and against matching, a means of assessing the degree to which deviations may be regarded as systematic must be established.

Measurement of Deviations

As mentioned in the previous section, an algebraically equivalent form of Equation 1.1 is

$$\frac{R_1}{R_2} = \frac{r_1}{r_2} \qquad (2.1)$$

Staddon (1968) first suggested that systematic deviations from matching could be measured by a variant of this equation:

$$\frac{R_1}{R_2} = b\left(\frac{r_1}{r_2}\right)^a \qquad (2.2)$$

By fitting such an equation to the data the values of the two parameters may be obtained and the degree of deviation from matching assessed by the values of these parameters. When $\underline{a}$ and $\underline{b}$ are both equal to 1.0 Equation 2.2 reduces to the matching relation, in the form of Equation 2.1. The simplest and most common method of obtaining values for the two parameters is to use Equation 2.2 in its logarithmic form:

$$\log (R_1/R_2) = a \log (r_1/r_2) + \log b \qquad (2.3)$$

Simple linear regression of the logarithms of the response ratios on the logarithms of the reinforcement ratios will yield values for a and b.

Many experiments measure time allocation in addition to, or instead of, response rate. Equivalents to Equations 2.1, 2.2 and 2.3 may be written, substituting T_1 for R_1 and T_2 for R_2. T_1 is the time spent responding on the first schedule, and T_2 the time spent responding on the second.

Staddon (1968) showed that his data, to be discussed below, deviated systematically and substantially from matching, but were well accounted for by Equation 2.2. Since then the majority of experiments reporting deviations from matching have used the framework of Equation 2.2 to do so. Staddon (1968, 1972) has suggested that Equation 2.2 may be the more general relation, while Equations 1.1 and 2.1 may apply only in particular instances.

Baum (1974a) reviewed evidence of systematic deviations from matching using Equation 2.2. He described deviations of b from 1.0 as bias. This may arise because one manipulandum requires slightly more force than the other, or one feeder may give a slightly longer access time than the other. Unless such differences form part of the experimental design, bias reflects some unaccounted for asymmetry between the two alternatives.

Baum described values of a greater than 1.0 as overmatching and of a less than 1.0, undermatching (a term first used by Fantino, Squires, Delbrück and Peterson, 1972). The parameter a may be regarded as a measure of the sensitivity of the organism to the contingencies. Thus if the organism's behaviour is characterized by undermatching it is more indifferent to the asymmetry in the reinforcement rate between the alternatives than would be predicted by Equation 2.1. An organism which is overmatching is demonstrating a more extreme preference for the more lucrative alternative than would be predicted by matching. (Note that these deviations assume no bias. If there is bias, the subject may not be nearer indifference when undermatching and showing extreme preference when overmatching).

Baum differed from Staddon in his approach to deviations from matching. Rather than accept the power function as more general, Baum suggested consideration of Equation 2.1 as the basic relation. Deviations from this original matching law should be then regarded as errors whose sources are to be understood. Myers and Myers (1977) criticised this approach, suggesting that it "approximates a hypothetico-deductive approach to concurrent theory". They regarded terms such as undermatching simply as descriptors, while experimentation should be directed at elucidating the conditions under which the parameters of Equation 2.2 adopt their various values.

Such differences of opinion need not lead to differences in the interpretation of data. If, for example, a certain variable is found to influence the slope of Equation 2.3, the information may be used in the manner suggested by Baum, or according to Myers and Myers' view. We may say that if matching is to be obtained that variable must be set within the appropriate range, while it may also be possible to discover the precise relation between that variable and the parameter <u>a</u>. The issue is important only when we come to consider the implications of the matching law and the longer term aims of research. What is important here is whether we can identify the factors which contribute to deviations from matching.

<u>The Evidence</u>

Most of the experiments discussed in Section 2.2 did not report a fit of Equation 2.2 to the data. Evidence of conformity to matching was based principally on visual inspection of graphs which plotted the data and the prediction of the matching law. In this section the extent of deviations from matching will be assessed more critically by means of Equation 2.2.

Two reviews of extant data have attempted to evaluate the evidence for and against consistent deviations from matching. Myers and Myers (1977) fitted Equation 2.3 to the data obtained by Herrnstein (1961), Catania (1963a), Silberberg and Fantino (1970) and Trevitt, Davison and Williams (1972). The results, with the exception of the fit to Herrnstein's data, showed consistent undermatching. When Equation 2.3 was fitted to the combined data from all of the experiments the values for the two parameters were $a = 0.84$ and $b = 0.95$. Thus, while bias was negligible, undermatching was fairly strong and consistent.

Myers and Myers fitted two other equations to the data:

$$\frac{R_1}{R_1+R_2} = c \frac{r_1}{r_1 + r_2} + d \qquad (2.4a)$$

and

$$\frac{T_1}{T_1+T_2} = e \frac{r_1}{r_1 + r_2} + f \qquad (2.4b)$$

The parameters $\underline{c}$ and $\underline{e}$ reflect the sensitivity of the organism to the difference in the reinforcement rate between the alternatives, as $\underline{a}$ does in Equation 2.2, while $\underline{d}$ and $\underline{f}$ reflect bias in the same way as log $\underline{b}$. When Equation 2.4a was fitted to the combined data, the values of the two parameters were $c = 0.90$ and $d = 0.05$. For Equation 2.4b the values were $e = 0.95$ and $f = 0.02$. Equation 2.4b was applied to a smaller set of data than Equation 2.4a since only the last three of the experiments listed above measure time allocation.

Whichever equation is used, the results seem to convincingly demonstrate that response ratios (or proportions) tend to undermatch rather than match reinforcement ratios (or proportions). Myers and Myers concluded from their analysis that Equation 1.1 was contradicted by the data. All the experiments cited above employed pigeons reinforced with food on concurrent VI VI schedules and with a COD in operation. Thus, from consideration of the experiments which most closely resemble Herrnstein's (1961) original, Myers and Myers were able to suggest that undermatching and not matching was the appropriate generalization. The evidence from fitting Equation 2.4b was much less convincing and did not enable any such generalization.

In another review, de Villiers (1977) came to a less radical conclusion from the same type of analysis. de Villiers used Equation 2.2 in both response and time ratio form, and, in addition, found the value of b and the proportion of variance accounted for when a was restricted to a value of 1.0 (i.e. matching with variable bias). The data used for fitting response ratios to reinforcement ratios came from the four studies considered by Myers and Myers, plus experiments by Baum (1972, 1974b) and McSweeney (1975). For time ratios, the experiments analysed by de Villiers in addition to those used by Myers and Myers were Brownstein and Pliskoff (1968), Baum and Rachlin (1969), Stubbs and Pliskoff (1969) and Baum (1975).

Most instructive is the difference in the proportion of variance accounted for when a was free to vary and when its value was set at 1.0. Considering only the group data from each experiment (which in the case of Baum (1972) came from only one subject), fitting log response ratios to log reinforcement ratios showed that the proportion of variance accounted for by a line with unit slope varied from 84% to 99%. With the slope free to vary the range was 87% to 99%. The maximum discrepancy between the two variance proportions was 8% (from the data of Trevitt et al, 1972), while in every other case the difference was less than 5%. When log time ratios were fitted to log reinforcement ratios the equivalent figures came out as matching range: 86% to 97%; free slope range: 88% to 98%; maximum discrepancy: 2%.

The results of de Villiers' analysis raise a very important issue not considered by Myers and Myers. While a line of best fit may show considerable deviation from the standard or ideal, that standard may be only slightly less accurate a description of the data. While response ratios tend to undermatch reinforcement ratios much more frequently than they overmatch them, it may be that parsimony should be given a higher priority than a slight increase in accuracy of prediction. The much simpler matching equation was proved to be only slightly inferior in its accounting for the data than Equation 2.2. The difference was much less for time than response data, and undermatching was less frequent for the former. de Villiers rightly concluded that there is little weight of evidence against matching of time ratios to reinforcement ratios. For response ratio data he suggested that matching holds only under certain conditions. If these are not properly controlled for (as many studies failed to do), the probability of obtaining undermatching is greatly increased. These factors include order effects, experimentally induced biasses and use of a COD of sufficient length. They will be discussed in more detail below.

Three recent experiments, not included in either of these reviews, support the generality of undermatching. Lobb and Davison (1975) employed both concurrent VI VI and concurrent VI FI schedules, but only data from the former will be considered here. For all five subjects response ratios undermatched reinforcement ratios, with group data yielding a value of $\underline{a} = 0.80$, accounting for 98% of the variance. Only group data were presented in raw form. When these were reanalyzed with the constraint that $a = 1.0$, 92% of the variance was accounted for. Thus, while there was consistent undermatching, matching still provided a good description of the data. Time ratios approximately matched response ratios for all subjects, with a = 1.07 for group data.

Davison and Hunter (1976) investigated performance in both two and three key concurrent VI schedules. Their group data from the three key schedules were reanalyzed. An assumption of response symmetry was made in taking no account of which two of the three keys were employed. For response ratios, a value of a = 0.64 was obtained, with the curve accounting for 96% of the variance in the data. With a set at 1.0 and b free to vary only 66% of the variance was accounted for. Time ratios also undermatched reinforcement ratios: the line of best fit showed a = 0.79 accounting for 98% of the variance. The non-error variance was reduced to 91% when a was set at 1.0.

Pliskoff and Brown (1976) also employed three component concurrent VI schedules. In reanalyzing the data, response, time and reinforcement ratios for schedules A and B were considered separately from those for schedules B and C since there was evidence of bias toward B. Using the A/B ratios the group data revealed a value of a = 0.70 (93% of the variance accounted for) for time ratios and a = 0.78 (85%) for response ratios. The equivalent results from reanalysis of the B/C data were: time ratios - a = 0.90 (92%) and response ratios - a = 0.84 (70%). Analysis of individual subjects' data revealed consistency amongst the values of a, but two of the three subjects had much less error variance than the third. Matching provided a good account of the data from these two subjects. However these results should be treated cautiously since several aspects of the procedure of this experiment differentiate it from most others described here. Firstly, a peck on the changeover key resulted in a switch only with a certain probability. Secondly, the subject could not control the schedule switched-into by a successful changeover. Because there was only one main key, a changeover in one direction (e.g. A to B) would require at least one response, and in the other direction (A to C) at least two. In addition a relatively small COD of 1.5 secs was employed. Any of these factors may have contributed to the undermatching observed in this experiment.

These three experiments, together with Trevitt et al (1972), provide the strongest evidence for systematic deviations from matching in the direction of undermatching. In common with most of the other experiments reviewed here, the results from this group indicate that response ratios are likely to deviate more from reinforcement ratios than are time ratios. However the reason for the greater degree of undermatching found in these experiments is not clear. It may perhaps be significant that three of the four have come from the same laboratory, since slight, as yet unknown, procedural variations may alter the value of a.

In a fourth recent experiment Norman and McSweeney (1978) exposed five rats to a variety of concurrent VI VI schedules. The group data showed that response ratios slightly overmatched reinforcement ratios ($a = 1.09$) while time ratios nearly matched reinforcement ratios ($a = 0.99$). In both cases the line of best fit accounted for 98% of the variance. While there was considerable inter-subject variation in the closeness with which matching was approximated and the direction of deviation, these results provide strong support for the matching law.

This survey has shown that matching provides at least a good description of the relation between time and reinforcement ratios. Although there is evidence of considerable deviation from matching, comparison of a range of experiments shows that these deviations are in the directions of both undermatching and overmatching. The exact nature of the relation between response and reinforcement ratios is less clear. The bulk of the evidence favours the conclusion that undermatching is most general, but in most instances matching is only slightly worse a predictor than the best fit line. de Villiers (1977) has pointed to methodological weaknesses in many of the experiments whose results contradict the matching law, and further research may verify that matching is found whenever these are avoided.

2.4. SOME LIMITS ON MATCHING

2.4.1. Introduction

The previous section introduced Equation 2.2 as a means of assessing deviations from matching. This equation will be used here to identify some of the variables which influence the closeness with which Equation 1.1 is approximated. Several of these have already been mentioned, but will be discussed below in greater detail. Others will be introduced, since in this section we will be concerned with the full extent of the applicability of the matching law.

An analysis of the variables which influence whether matching occurs or not may be viewed in two different ways. Firstly, we may see the endeavour as an attempt to define the boundary conditions of matching. Statements can then be made as to what values the controlling variables must assume for matching to occur. Secondly, we may simply catalogue the types of deviations which occur with the different values of each variable. These two approaches are respectively consistent with the two views of Equation 1.1 already outlined: that it is an empirical standard and that it is only one of a family of such functions.

No firm commitment to either of these views can be given without a consideration of the evidence. It was concluded in the previous section that there is considerable evidence for regarding at least matching of time ratios to reinforcement ratios as a standard. It remains to be seen whether such standards can be maintained across a much broader range of experimental conditions.

2.4.2. Changeover Contingencies

Matching and the COD

Beginning with Herrnstein (1961), a number of experiments have shown that the use of a COD is critical for the occurrence of matching. Most instructive in this regard is an experiment by Brownstein and Pliskoff (1968). Using a concurrent VT 1-min VT 3-min schedule of reinforcement they gradually increased the length of the COD for each subject until the reinforcement and time ratios were equal. The COD was then maintained at this length while relative reinforcement rate was varied. For the three pigeons used these terminal COD values were 2, 5 and 7.5 secs respectively. The resultant data demonstrated very close conformity of time ratios to reinforcement ratios in all subjects.

A second example was provided by a subject used by Baum (1975). With the COD set at 2 secs this subject's behaviour was characterized by strong undermatching, but when COD length was increased to 10 secs matching was closely approximated. Contrary examples exist however: Bradshaw et al (1976), again using human subjects, found matching with no COD. The reason for these rare exceptions is unclear.

While a certain minimum COD value is generally found necessary for matching, the relation appears to remain constant when COD length exceeds this value. That is, matching is not found only when COD length falls within a restricted range, but requires only a certain minimum value. This preserves a certain amount of the generality of the matching relation since it is clearly not an artifact of the particular COD values usually employed. Data illustrating this point have been discussed by de Villiers (1977) and come from experiments by Allison and Lloyd (1971), Shull and Pliskoff (1967) and Stubbs and Pliskoff (1969). The second of these used rats rather than pigeons and the reinforcer was electrical stimulation of the brain rather than food. In this experiment relatively high COD values of 5-10 secs were required for matching. Such values are usually employed when the subjects are rats.

The effects of the COD on local response rate patterns

Several experiments have attempted to elucidate the role of the COD in concurrent performances. Pliskoff (1971) and Silberberg and Fantino (1970) measured response rate both during the COD period and after it had terminated. The results of the two experiments concurred in finding that response rate was much higher when the COD was in operation than during the post-COD period. This high COD rate or burst actually extends slightly into the post-COD period before response rate drops to a lower, approximately constant level (Silberberg and Fantino, 1970).

Silberberg and Fantino also varied relative reinforcement rate while measuring both COD and post-COD response rates. While relative COD rate varied inversely with relative reinforcement rate, relative post-COD rate overmatched it. Overall relative response rate closely approximated relative reinforcement rate. Thus COD and post-COD response rates tend to vary in opposite directions as the distribution of reinforcements changes, but when combined they follow the orderly matching relation.

Pliskoff demonstrated that this difference between COD and post-COD responding tends to decrease with larger CODs. The greatest response rate difference was found when the COD was 1 sec, while COD response rate declines as COD size is increased from 1 to 27 secs. Post-COD response rate was relatively constant across this range. Since matching is dependent only on the COD being greater than 2-3 secs (for pigeons) it cannot be an artifact of a particular response rate difference.

This research questions the role of the COD in matching. While CODs reduce the probability of concurrent superstitions, it is not clear whether the particular pattern of local response rates associated with use of a COD is necessary for matching. Certainly, the amount of difference between COD and post-COD response rates is not critical, but whether some difference is remains to be shown. This matter will be discussed again in Chapter 4.

Matching and Changeover Rate

A second important effect of the COD on concurrent performance is the reduction of changeover rate. Shull and Pliskoff (1967) demonstrated that the rate of switching between schedules decreases as COD length is increased. If no COD is employed changeover responding may dominate the concurrent performance. An example of such behaviour was discussed by Schroeder and Holland (1969) in an experiment where subjects were required to detect pointer deflections in two pairs of dials, described above. When there was no COD subjects' eye-movements followed a Z-pattern: each dial was observed briefly in turn with continuous changing of gaze direction from side to side. The imposition of a COD eliminated this pattern, resulting in more eye-movements on each side between changeovers.

Such data raise the question of whether any procedure which reduces changeover rate may also result in matching. The COD may be necessary for matching simply because it punishes changeover behaviour, thereby reducing it to an appropriate level. Stubbs, Pliskoff and Reid (1977) have summarized data on three different changeover contingencies which are able to reduce changeover rates: CODs, CORs (changeover ratios - a fixed number of responses on the changeover manipulandum are required for switching between schedules) and TOs (time outs - following a changeover response all functions are stopped and the chamber is darkened for a fixed period of time). Power functions were found to give a good description of the relations between interchangeover time (the average length of time between switching-into and switching-out of a schedule) and COD, COR and TO size. Data from Todorov (1971), who showed that changeover rates were reduced when switching was punished with electric shock, were suggestive of such a relationship. Thus there are a number of alternative changeover contingencies which have effects on changeover rate analagous to those of the COD.

Todorov also provided data on relative time and relative response and reinforcement rates at different TO lengths and electric shock magnitudes. Using a concurrent VI 1-min VI 3-min schedule he found that as TO length or shock intensity increased the proportion of responses to the richer schedule increased, while relative reinforcement rate was virtually constant. Relative time also increased, but less reliably and significantly than relative response rate. Both relative time and relative response rate undermatched relative reinforcement rate at low TO and shock values and overmatched it at high values.

These data are shown in Table 2.1 where response, time and reinforcement proportions are compared under different magnitudes of three changeover contingencies. The COD data are from Shull and Pliskoff (1967) (note that their "ascending" and "descending" data have been combined here) while the TO and shock data are from Todorov (1971). Both experiments employed concurrent VI 1-min VI 3-min schedules. Clearly matching is produced simply as an artifact of particular shock and TO magnitudes, whereas matching of both time and responses is closely approximated so long as a certain minimum COD size is exceeded. Both time and response proportions rise in a similar manner whether the increase in magnitude is in TO, COD or shock intensity, but only in the case of the COD does the reinforcement proportion increase significantly as well.

These results suggest firstly that the reduction of changeover rate below a certain minimum level is not sufficient for time and response proportions to match reinforcement proportions. Secondly, as evidenced by the disparate effects of CODs and TOs, temporal separation of responses on one schedule from reinforcers on the other is not a sufficient condition for matching.

TABLE 2.1: Data from the experiments of Todorov (1971) and Shull and Pliskoff (1967).

Subject	Shock Intensity (mA)	Proportions		
		Responses	Time	Reinforcements
P1	0	.69	.58	.74
	4	.69	.54	.74
	7	.77	.61	.75
	10	.82	.70	.75
	16	.93	.83	.77
P2	0	.65	.69	.75
	4	.66	.70	.75
	7	.94	.84	.78
	10	.92	.73	.78

Subject	TO (secs)	Proportions		
		Responses	Time	Reinforcements
P12	0	.69	.74	.74
	0.3	.81	.77	.75
	1.0	.84	.78	.76
	3.0	.88	.80	.76
	9.0	.91	.86	.77
P13	0	.61	.66	.75
	0.3	.62	.71	.73
	1.0	.75	.69	.74
	3.0	.90	.80	[illegible]
	9.0	.95	.87	[illegible]

Subject	COD (secs)	Proportions		
		Responses	Time	Reinforcements
S1	0.0	.63	.54	.73
	2.5	.70	.60	.74
	5.5	.66	.66	.75
	7.5	.67	.74	.75
	10.0	.85	.80	.84
	12.5	.74	.80	.79
	20.0	.90	.87	.90
S2	0.0	.54	.52	.73
	2.5	.64	.61	.74
	5.0	.62	.60	.74
	7.5	.70	.68	.75
	10.0	.71	.73	.78
	12.5	.75	.77	.79
	20.0	.88	.88	.90

Conclusion

Two effects of the COD on concurrent performances have been examined with a view to finding which aspect of the COD makes it critical for matching. It was concluded above that reduction of changeover rate was not the critical variable. It is possible that matching is dependent on the particular post-changeover response rate pattern produced by the COD. However the fact that this pattern becomes less prominent at larger COD values argues against this. Until the critical aspect or aspects are isolated, the generality of matching is somewhat limited by the need to employ a COD. This issue will be discussed further in Chapter 4, where the COR will be considered as an alternative to the COD.

2.4.3. Time matching vs Response matching

A number of the experiments which have already been discussed have shown that the allocation of behaviour between several alternatives can be measured in two different ways. Either the amount of time allocated to each alternative or the number of responses made to each may be used as the dependent variable. When there is no explicit, discrete response only time allocation can be measured (e.g. Baum and Rachlin, 1969), but the majority of experimental arrangements allow measurement of both.

It is clear from the experiments discussed above that response rate has been the more popular dependent variable. Several possible explanations for this difference may be suggested. Firstly, it is the traditional datum of the experimental analysis of behaviour (Skinner, 1966), and is the most conspicuous defining characteristic of that area of research. Secondly, it was in terms of response measures that the matching law was first proposed by Herrnstein (1961). The third possible reason relates to practical aspects of measurement: with traditional controlling and recording equipment counting of responses is easier than measurement of time periods. This is particularly so when there is no explicit changeover response (i.e. each alternative is associated with a different manipulandum), since the exact time of a changeover cannot be defined.

Nevertheless, a significant number of experiments have measured time allocation in addition to response rate, or as the sole dependent variable. The results of these experiments may be used to assess whether matching is confined to the relation between relative time and relative reinforcement rate, or whether response matching is as valid a relation. It was concluded in Section 2.3 that the evidence for time matching was much stronger than that for response matching. It may be that while time matching is an empirical standard, the sensitivity of response rate to a broader range of factors results in a family of functions describing the various relations between relative response rate and relative reinforcement rate.

Firstly, however, another proposition will be discussed: that response matching is a natural consequence of the more fundamental time matching. The evidence to be discussed below will also enable an assessment of this hypothesis to be made.

Time matching as fundamental

While several authors have argued for the fundamental nature of time matching, this view has been discussed most clearly by Rachlin (1973). His basic premise is that whatever the distribution of reinforcements between the alternatives, local response rate tends to be equal across the alternatives (e.g. Killeen, 1972b). Thus response matching occurs not because the organism responds at a greater rate to the more lucrative alternative, but because it spends more time responding at the same rate. Accordingly, whenever relative time matches relative reinforcement rate, relative response rate must also match relative reinforcement rate. More generally, Rachlin's hypothesis predicts that the value of the parameter $\underline{a}$ in Equation 2.2 should be the same whether the left-hand side is the ratio of times or response rates.

Rachlin suggested that time is allocated between alternatives so as to equate the two local reinforcement rates. With concurrently programmed VI schedules, the more time that is spent responding on one alternative, the greater the probability of reinforcement for a response on the other. The rate of increase of this probability depends on the particular values of the VI schedules. By matching relative time to relative reinforcement rate the organism balances these probabilities by equalizing the local reinforcement rates.

Experiments measuring time allocation only

Concurrent schedules may be programmed with reinforcement independent of any particular response. A means of switching from one alternative to the other is provided and the reinforcers are delivered automatically according to the schedule the organism has chosen. The response-independent analogues of VI schedule, variable-time (VT) schedules, are usually employed in studies of matching. An experiment described earlier, Baum and Rachlin (1969), exemplifies such procedures. The switching response was moving from one side of the chamber to the other, and reinforcers were delivered as long as the pigeon was on the appropriate side. Ratios of allocated time approximated reinforcement ratios except for a coefficient accounting for bias to one side (for group data a = 1.01).

In a very similar experiment Baum (1973b) used time-out from electric shock rather than food as the reinforcer. (Experiments employing aversive stimuli will be discussed in more detail in Section 2.6, but will be mentioned here if they provide relevant data). For two of the four subjects, time ratios closely approximated reinforcement ratios. Results from a third were characterized by strong undermatching, while strong overmatching was shown by the fourth. Because the deviations were not systematic, the group data showed extremely close conformation to time matching. Baum suggested that the inter-subject differences were due to difficulties in experimental control associated with the use of electric shock.

Poling (1978) virtually replicated Baum's experiment but with rats instead of pigeons. Reanalysis of his data showed that for all three subjects time ratios undermatched reinforcement ratios (a = .96, .91 and .74 respectively). One important difference in the way time was measured may have influenced the difference in results between the two studies: Baum did not include time spent in the middle of the chamber, while Poling's data included such time.

Two other experiments have required a response on a changeover key for switching between schedules. This method eliminates the difficulties associated with a non-discrete switching response mentioned above. In Brownstein and

Pliskoff's (1968) experiment subjects allocated time between response independent schedules of food reinforcement. Time ratios closely approximated reinforcement ratios with group data yielding a value of a = 0.94. Bauman, Shull and Brownstein (1975) measured time allocation in both concurrent VI VI and concurrent VI VT schedules. The time distribution did not appear to be affected by the presence or absence of a response requirement. Matching of time ratios to reinforcement ratios was closely approximated, with some tendency to undermatching in data from two of the four subjects.

The final experiment to be mentioned here, Baum (1975), has also been described above. Human subjects were required to detect unpredictable signals by holding down either of two keys. With appropriate adjustments of response cost and COD length time ratios closely approximated reinforcement ratios. Deviations were in the directions of both undermatching and overmatching.

This survey of the extant data has demonstrated that when there are no discrete responses to be counted, the distribution of time across alternatives is related in an orderly fashion to the distribution of reinforcements. In most instances matching has provided a good description of the data, with some slight tendency for relative time to undermatch relative reinforcement rate.

Experiments measuring time allocation and response rate

The experiments which are crucial in assessing whether relative reinforcement rates are matched better by relative time or relative response rate and whether time matching is the fundamental relation are those in which both allocated time and response rate have been measured. It was demonstrated above that time provides a good measure of behaviour when there are no discrete responses. This section will be concerned with the relative merits of the two measures in cases whether either can be used.

There is a total of eight experiments which have employed concurrent VI schedules of positive reinforcement with a COD and have measured both time allocation and response rate. These are listed in Table 2.2 together with the values of a obtained from fitting response ratios and time ratios to reinforcement ratios using Equation 2.2 (group data only).

TABLE 2.2: Studies measuring both time allocation and response rate, with values of a from fitting time ratios and response ratios to reinforcement ratios.

Study		Values of a	
		Resp. ratio	Time ratio
Catania (1963b)		0.80	0.89
Davison and Hunter (1976)		0.64	0.79
Lobb and Davison (1975)		0.80	1.07
Norman and McSweeney (1978)		1.09	0.99
Pliskoff and Brown (1976)	(1)	0.78	0.70
	(2)	0.84	0.90
Silberberg and Fantino (1970)		0.85	1.07
Stubbs and Pliskoff (1969)		1.01	1.11
Trevitt, Davison and Williams (1972)		0.76	0.88

The results clearly show that systematic deviations from matching are more likely with the fit of response ratios to reinforcement ratios. In only two instances is a closer to 1.0 for response ratio fits. Both response and time ratios tend to deviate from reinforcement ratios predominantly in the direction of undermatching. Note, however, that the Pliskoff and Brown (1976) data should be regarded with caution for reasons described above. If these are excluded, time ratios deviate about equally commonly in the directions of overmatching and undermatching. Deviations of response ratios remain mostly as undermatching however. The clear implication of these results is that time ratios better approximate reinforcement ratios than do response ratios.

Rachlin's (1973) hypothesis may also be tested using the information in Table 2.2. As noted above, if local response rates are equal for the two alternatives, the values of <u>a</u> from the fits of response ratios and time ratios should be the same. (So also should the values of <u>b</u>. However, since there is little extant data showing strong biasses, this matter will be left for discussion in Chapter 3). This prediction is contradicted by the survey of results in Table 2.2, where in all but two instances, <u>a</u> is greater for time ratios than response ratios.

A reanalysis of data from two of Stubbs and Pliskoff's (1969) subjects, presented in Table 2.3, may be used to illustrate the implications of this difference. As can be seen from the lines of best fit, the two <u>a</u> values were in perfect agreement for P104, while for P108 <u>a</u> was greater when time ratios were fitted to reinforcement ratios. From the local response rate data, as the schedule arranging key 1 reinforcements became more lucrative, for P108 the ratio of key 1/key2 local response rates decreased from 1.24 to 0.72. By contrast, the local response rate ratio is approximately constant and close to 1.0 in the case of P.104.

These results clearly illustrate that if a is greater for time than response ratios, local response rate is higher in the less lucrative alternative. Since differences in the values of a are almost always in this direction, Rachlin's hypothesis appears to be disproved.

TABLE 2.3: A Reanalysis of the data from two of Stubbs and Pliskoff's Subjects.

	Least-squares Regression Lines	
	Response ratios	Time ratios
P104	$Y = 1.25X - 0.01$	$Y = 1.25X - 0.00$
P108	$Y = 0.94X + 0.02$	$Y = 1.07X + 0.02$

	Proportion of reinforcements from key 1	Local response rates		
		Key 1	Key 2	ratio
P104	0.25	69.91	75.63	0.92
	0.50	62.33	58.01	1.07
	0.75	67.06	70.22	0.95
	0.90	64.07	66.41	0.96
P108	0.25	53.68	43.39	1.24
	0.50	53.21	56.90	0.94
	0.75	41.55	48.33	0.86
	0.90	41.52	57.69	0.72

Some data from Logue and de Villiers (1978) demonstrate that this difference in a values is not confined to schedules of positive reinforcement. Rats were reinforced with shock avoidance according to two concurrent VI schedules. For both subjects, response ratios undermatched reinforcement ratios and time ratios overmatched reinforcement ratios.

One possible explanation for the fact that local response rates tend to be lower in the more lucrative alternative lies with the COD. As noted above, response rate is faster during COD than post-COD periods. If both COD and post-COD response rates are equal for the two alternatives, because COD time comprises a greater proportion of the total time allocated to the less preferred alternative, the overall local response rate will be faster for this schedule. However data from Silberberg and Fantino (1970) suggested that COD response rate tends to be faster for the less lucrative alternative. Thus, Rachlin's hypothesis is not tenable in an amended form which considers COD and post-COD responding separately.

Conclusion

This review of the relevant data has shown that when a COD is employed in concurrent VI schedules, time ratios better approximate reinforcement ratios than do response ratios. The deviations of response ratios are most commonly in the direction of undermatching. In addition, Rachlin's proposition that time matching is more fundamental than response matching has been shown to be based on a false premise: that local response rates are equal across alternatives.

These conclusions are constrained by the limited range of procedures considered here. In the next section the application of the matching law to concurrently programmed schedules other than VI will be considered. Evidence from these experiments may or may not add further support to the proposition that matching is limited to the relation between time and reinforcement ratios. In Chapter 4 the COR will be considered as an alternative to the COD. Data from two recent experiments (Marcucella and Margolius, 1978, and Pliskoff, Cicerone and Nelson, 1978) and experiments to be reported in Chapter 4, show that when this changeover contingency is employed response ratios tend to deviate from reinforcement ratios in the direction of overmatching. However, with this contingency time ratios better approximate reinforcement ratios than do response ratios, so that the two basic conclusions above are not altered by these findings.

2.4.4. Different Schedule Types

One factor which is crucial to an assessment of the generality of the matching law is the type of schedules which are concurrently programmed. To this stage conclusions have been made almost solely with reference to concurrent VI schedules. If similar results are obtained when other schedule types are used, matching may be extended to a much wider variety of concurrent performances. In this section a number of experiments which yielded data enabling an assessment of matching, and employed schedules other than simple VI, will be briefly described.

Different VI types

In several experiments second-order schedules, in which the unit of behaviour reinforced according to a VI schedule is the completion of the requirement of another schedule (these have been termed "unit schedules" by Gollub, 1977), have been concurrently arranged. The unit schedule in Cohen's (1975) experiment was an FI. With the FI schedules the same for both alternatives, both relative time and relative response rate closely approximated relative reinforcement rate. Variations in the size of the FI unit schedule for one alternative revealed consistent bias toward the alternative with the shorter FI. There was considerable inter-subject variation in the magnitude of this bias.

FR unit schedules were used in an experiment by Beautrais and Davison (1977). The values of the VI schedules were varied both when the unit schedules were equal and when they were unequal across the alternatives. Both time and response ratios undermatched reinforcement ratios in the two sets of conditions. One surprising aspect of the data was that bias toward the alternative with the smaller FR unit schedule was evident in the response ratios but not in the time ratios. The rationale for this difference is not clear.

Chained schedules of reinforcement are also encompassed by the definition of second-order schedules given above. A series of experiments using concurrent chains by Autor (1969) were described as supporting the matching law. However more recent research, principally by Fantino and his associates, has demonstrated the inadequacy of Equation 1.1 in handling data from concurrent chains. These experiments will not be discussed here since an excellent review has been given by Fantino (1977). The alternative ("delay reduction") hypothesis suggested by Fantino is expressed in the equation

$$\frac{R_1}{R_2} = \frac{(T - t_1)}{(T - t_2)} \quad \frac{r_1}{r_2} \qquad (2.5)$$

where T is the "average delay to primary reinforcement from the onset of either initial link" (Fantino, 1977; his italics), t_1

and t_2 are the average durations of the respective terminal links and r_1 and r_2 the terminal-link reinforcement rates. Note that unlike a simple matching relation, this equation predicts that choice depends on the absolute durations of the initial links: preference is more extreme the shorter these durations. The research on concurrent chains has demonstrated one way in which the matching equation may be modified so as to account for a wider range of data.

Several experiments have employed concurrent VI schedules combined in different ways. Both Pliskoff, Shull and Gollub (1968) and Lobb and Davison (1977) programmed two multiple VI schedules each with a common VI schedule concurrently available. The overall schedule may therefore be considered a multiple (concurrent VI_1VI_2) (concurrent VI_1VI_3). Pliskoff _et al_ showed that for both concurrent schedules relative response rate closely approximated relative reinforcement rate, with deviations principally in the direction of undermatching. Lobb and Davison's data indicated that response ratios consistently undermatched reinforcement ratios. Both the degree and direction of deviation was similar to that which has been obtained with concurrent VI VI schedules in the same laboratory (e.g. Lobb and Davison, 1975). In neither experiment were time allocation data reported.

Menlove, Moffitt and Shimp (1973) concurrently programmed two concurrent VI VI schedules. Matching of relative response rate to relative reinforcement rate was closely approximated for both choice between concurrent VIs and choice between concurrent VI VI schedules.

While most of the results presented in this section are similar to those obtained with standard concurrent VI schedules, further research may show that there are difficulties associated with application of the matching law. It is worth noting that concurrent chains schedules have attracted most research, and it is in application to the behaviour generated by these schedules that the matching law has been found inadequate.

Concurrent schedules with FI components

The results of the manipulation of relative reinforcement rate in concurrent FI VI schedules have been reported in three experiments. All agree in suggesting that undermatching is stronger when there is an FI component than when two VI schedules are concurrently arranged. Nevin (1971) recorded the strongest departures from matching: $\underline{a}$ values of approximately 0.5 for the relation between response and reinforcement ratios. White and Davison (1973) and Lobb and Davison (1975) reported both time ratios and response ratios in experiments in which subjects were also exposed to concurrent VI VI schedules. With two minor exceptions undermatching was stronger in the data from concurrent FI VI schedules. Even in Lobb and Davison's experiment where time ratios slightly overmatched reinforcement ratios for concurrent VI VIs, time ratios undermatched reinforcement ratios (for group data $\underline{a} = 0.72$) in concurrent FI VI performance.

With the exception of one pigeon used by Nevin (1971), subjects in all three experiments demonstrated a bias toward the alternative where reinforcements were arranged according to a VI schedule. In the two experiments reporting time ratios, the bias was consistent whether time or response ratios were considered.

Performance in concurrent FI FI schedules has been examined in two experiments. In Shimp's (1971b) experiment variations in the value of the two FI schedules resulted in approximate equality between relative response rate and relative reinforcement rate. Deviations were more indicative of bias than of overmatching or undermatching. More interesting results came from the experiment of White and Davison (1973). For all subjects response ratios undermatched reinforcement ratios, with group data yielding a value of $\underline{a} = 0.81$. However, the deviations from matching consistently occurred in four of the conditions. If these are excluded the group data shows an $\underline{a}$ value of 1.03 and the fitted line accounts for 99.9% rather than 93% of the variance. The pattern of results from analysis of the time ratio data was similar, though less pronounced.

The interesting aspect of these results is the fact that the pattern of responding revealed by inspection of cumulative records was deviant for this set of conditions. In all other conditions the pattern of responding in both alternatives was typical of that found in simple VI or simple FI schedules, while for these four conditions performance on the shorter FI was typical of FI responding and on the longer it more closely resembled VI responding. The only generalization which can account for the difference in response patterns is that performance on an FI schedule concurrently arranged with a second will only show the typical FI pattern if the duration is 50 secs or less.

This suggests that matching in concurrent schedules with one or more FI components depends on the pattern of responding being the same in both alternatives. For concurrent FI VI schedules this would mean that the pattern in the FI component would have to be similar to that usually generated by VI schedules. With concurrent FI FI schedules all that is required is symmetry in the patterns: either both typical FI or both typical VI. The reason why matching should be bounded by such pattern requirements is not clear. It certainly suggests that more detailed analysis of patterns of local response and reinforcement rates is needed to understand the conditions under which matching is found on concurrent schedules with FI components.

Concurrent schedules with ratio schedule components

Special consideration must be given to the predictions of the matching law when one or more of the concurrently arranged schedules is either an FR or a VR. Whereas reinforcement rate is largely independent of response rate for interval schedules (given the response rates usually observed), there is a direct proportionality for ratio schedules. That is,

$$R = n\,r \tag{2.6}$$

where n is the ratio size. Returning to Equation 1.1 we find that with two ratio schedules

$$\frac{R_1}{R_1 + R_2} = \frac{R_1/n_1}{R_1/n_1 + R_2/n_2} \tag{2.7}$$

If $n_1 \neq n_2$ this equation is true only if responding is exclusively to one alternative, i.e. if $R_1 = 0$ or $R_2 = 0$. Our assumptions about behaviour would lead us to expect that the organism would choose the alternative for which the ratio size was smaller.

The results of an experiment by Herrnstein and Loveland (1975) suggested that the behaviour of pigeons conforms to this prediction. They arranged two concurrent VR schedules and varied the sizes of the two ratios, both with and without a COD. The subjects' behaviour closely approximated exclusive preference for the alternative with the smaller VR, irrespective of whether the COD was in force or not. Similar results were also obtained in an experiment by Herrnstein (1958).

The prediction of Equation 2.7 contradicts a large amount of data from research on probability learning. Experiments in this area usually require subjects to predict which of two stimuli will appear in each trial by responding on one of two manipulanda. The schedule is thus concurrent VRx VRy, where $\frac{1}{x} + \frac{1}{y} = 1.0$ (since one of the stimuli appears on each trial), with no COD. When $x \neq y$ one of two patterns of behaviour is usually observed: responding is exclusively to the alternative with the most frequently appearing stimulus (maximizing) or the ratio of responses equals the ratio of probabilities, $(\frac{1}{x})/(\frac{1}{y})$ (probability matching) (Mackintosh, 1974). Only the former conforms to the matching law.

The extensive literature on probability learning will not be discussed here (see Bitterman, 1969, and Sutherland and Mackintosh, 1971, for reviews). Variations in subjects, procedure, amount and type of reinforcement, etc., make comparison among experiments difficult. However, the fact that probability matching has been frequently reported suggests that if the matching law is to attempt to account for these data it may have to be modified so as not to be limited to the conditions under which maximimizing is observed. Unfortunately, the exact conditions are not easily specified at this point (but see

Greeno, 1968, for some hypotheses and alternative equations to account for probability matching and maximizing).

In several experiments concurrent schedules with one interval and one ratio component have been programmed. It follows from Equations 1.1 and 2.6 that the response distribution in such schedules should obey the relation

$$\frac{R_1}{R_1+R_2} = \frac{n_1r_1}{n_1r_1+xr_2} \tag{2.8}$$

That is, matching requires that the subject adjust its response rate on the interval schedule such that the number of responses per reinforcement is the same for both schedules, i.e. $x = n_1$. Herrnstein (1970) tested this prediction using concurrent VI VR schedules. At most schedule values responding was exclusively to one alternative or the other, but even when this was not the case response proportions closely approximated reinforcement proportions.

In a virtual replication of this experiment by Herrnstein and Loveland (reported by de Villiers, 1977) similar results were obtained. Response ratios closely approximated reinforcement ratios with values of a varying from 0.92 to 1.06. Allocated time was also measured in this experiment. Time ratios tended to undermatch reinforcement ratios: a varied from 0.70 to 1.01. However group data revealed close approximation to both time and response matching.

Bacotti (1977) varied both FR size and COD length in concurrent FR VI schedules. Both response and time ratios slightly overmatched reinforcement ratios (a = 1.09 to 1.16 for response ratios and 0.95 to 1.15 for time ratios), with strong and consistent bias toward the alternative scheduling reinforcements according to a VI. COD length did not appear to affect these results. Bacotti suggested two possible explanations for the observed bias: one relies on the fact that there is a longer average delay between a changeover and reinforcement for the FR alternative, and the other on the existence of short inter-reinforcement intervals for the VI but not the FR component. Both are consistent with several results (including the fact that bias is weak or non-existent in the case of concurrent VI VR schedules).

Concurrent VI FR performance has been examined in two experiments. LaBounty and Reynolds (1973) varied the FR requirement while maintaining the constancy of the value of the VI schedule. de Villiers (1977) has reanalyzed their data in terms of ratios rather than proportions. One of the six pigeons showed aberrant behaviour in either being indifferent between the alternatives or responding exclusively on the FR alternative. For the other five subjects, response ratios undermatched reinforcement ratios ($\underline{a}$ = 0.75 to 0.89) as did time ratios ($\underline{a}$ = 0.66 to 0.99). This strong undermatching may be explicable in terms of the explanation for White and Davison's (1973) data given above, but the cumulative records shown by LaBounty and Reynolds do not enable verification of such an hypothesis.

The second of these experiments was one by Wood, Martinez and Willis (1975). When their data were reanalyzed to assess conformity to the matching law, very poor fits were obtained with deviant parameter values. These unusual results may be attributable to a degree of divergence from the procedures customarily used, and for this reason should be given little weight.

The matching law seems to generalize well to performance in concurrent schedules with FR or VR components. Several issues remain however. Firstly, there is the problem of probability matching. Further experimentation is required linking the two areas of research. The second problem is one which is general to all research extending matching to apply to non-VI schedules: the idiosyncracies of performance on certain schedules sometimes generate bias and undermatching which are difficult to explain. Particularly troublesome in this regard is FI performance, and Bacotti's (1973) results suggest that behaviour under FR schedules may present as many difficulties. The obvious direction of future research lies in detailing the various patterns of responding and finding which cause deviation from matching and which result in conformity.

2.4.5. Schedules of Aversive Stimulation

One variable which may affect the extent to which the matching law accurately reflects concurrent performance is the type of reinforcer employed. While several different types of positive reinforcers have been used in experiments already described, little has been said of the applicability of the matching law to behaviour generated by schedules of aversive stimulation. The relevant experiments, to be reviewed here, fall into two categories: those concerned with the effects of punishment and those examining escape or avoidance behaviour.

Escape and Avoidance Schedules

Several of the experiments to be discussed here have been mentioned above. In one of these (Baum, 1973b), pigeons were reinforced for standing on one side of the chamber or the other with time-outs from electric shock arranged by two concurrent VI schedules. Standing on one side was reinforced according to one VI schedule and standing on the other was reinforced according to the second VI. Shocks were delivered at the rate of one per second while TO lasted two minutes. A 1 sec COD was enforced. The group data showed that time ratios closely approximated reinforcement ratios ($\underline{a} = 1.01$), but there was considerable inter-subject variation (range of $\underline{a}$ values was 0.38 to 1.50). Baum suggested that this variation may be attributable to difficulties associated with the use of electric shock schedules (technical problems, pronounced hysteresis effects, etc.).

In a second experiment already described, Poling (1978) found that with rats time ratios undermatched reinforcement ratios in an experiment very similar to Baum's. It was suggested that the reason for the difference in the results may lie in the fact that Baum did not include time spent in the middle of the chamber, whereas in Poling's experiment all time was considered to have been spent on one side or the other.

Logue and de Villiers (1978) reinforced rats' bar-presses with shock avoidance according to two concurrent VI schedules (see de Villiers, 1974, for a discussion of this type of avoidance schedule). The pattern of results was the same for the two subjects used: response ratios undermatched reinforcement ratios ($\underline{a} = 0.92$ and 0.82) and time ratios overmatched reinforcement ratios (a = 1.32 and 1.22). (Reinforcement ratios were of the form: shocks avoided in schedule 1/shocks avoided in schedule 2). Such results parallel those obtained with concurrent VI schedules of positive reinforcement, but the difference in slopes obtained from response and time data is much greater.

Hutton, Gardner and Lewis (1978) reinforced pigeons' pecks on two keys with time-out from electric shock. In the absence of responding the average interval between shocks was 5.4 secs, while reinforcements were arranged according to two concurrent VI schedules. Both time and response ratios consistently undermatched reinforcement ratios: a values ranged from 0.60 to 0.78 for response ratios and 0.57 to 0.84 for time ratios. Such strong undermatching may be partially explained by the fact that no COD was employed in this experiment. The authors suggested that use of a COD tends to lead to exclusive preferences.

Logue (1978) reinforced rats' presses on two bars with time-out from intense white noise according to pairs of concurrent VI schedules. For all subjects response ratios deviated strongly from reinforcement ratios in the direction of undermatching. When the results from all subjects were combined the value of a was 0.69, accounting for 90% of the variance. Logue suggested two reasons for the pronounced undermatching observed. Firstly, he used a COD of only 1 sec, a value which Shull and Pliskoff's (1967) results would suggest was too low for rats. Secondly, there was some evidence that order effects increased the likelihood of undermatching.

These experiments provide conflicting data which make an assessment of conformity to matching difficult. In different experiments time ratios have been found to undermatch, match and overmatch reinforcement ratios, while in only three experiments have response rates been measured. It may be that greater variability is inherent in the use of shock rather than food (e.g. see Baum's 1973b discussion), or that other unidentified factors associated with the use of aversive stimuli determine the degree and direction of deviation from matching.

Punishment schedules

Deluty and Church (1978) arranged two concurrent VT schedules of shock delivery. A single bar-press was required for switching between schedules. They suggested that subjects should allocate time to the two alternatives according to the equation

$$\frac{T_1}{T_1+T_2} = \frac{P_2}{P_1+P_2} \qquad (2.9)$$

where P_1 and P_2 are the obtained rates of punishment for the respective alternatives. They employed two different sets of conditions. In the first, each VT timer was stopped when the subject switched-out of that component and restarted when it switched back in. Thus, only one VT timer was in operation at any one time. Results from this set of conditions indicated close approximation to Equation 2.9, but with a slight tendency to undermatching for all three subjects. In the second phase, the usual procedure in which VI timers are not halted by changeovers was employed. Relative time was negatively correlated with relative punishment rate (excepting conditions in which only one schedule was arranging shocks). Deluty and Church suggested that in this phase subjects were minimizing: allocating almost all of the time to the alternative associated with the lower shock rate.

These results can be understood if the contingencies on switching are considered. The longer time spent in one component, the more likely it is that a punishment has been "set up" by the other VI timer. If this is so, then a shock will follow immediately after the COD has elapsed (COD = 2 secs in this experiment). When these contingencies were not present, as in the first phase of the experiment, matching occurred. Matching was therefore dependent on switching not decreasing the likely delay to the next shock.

Deluty (1976) examined the effects of added punishment in schedules of food reinforcement. Rats' bar-presses were reinforced according to two equal concurrent RI schedules. (RI schedules generate similar response patterns and rates to VI schedules, Farmer, 1963). In addition, punishment was programmed according to two independent RI schedules of electric shock. The rate of punishment scheduled for one alternative was kept constant while the other was varied. He found that an equation of the form

$$\frac{R_1}{R_1+R_2} = \frac{r_1 + P_2}{r_1+r_2 + P_1+P_2} \qquad (2.10)$$

accounted for 88% of the variance in the group data. As Deluty indicated, Equation 2.10 assumes equality of magnitude between one reinforcer and one punisher. Appropriate scaling may improve the ability of this equation to describe the results.

Such scaling was undertaken by Farley and Fantino (1978) in an experiment employing the concurrent chains procedure. The initial links were VI 1-min schedules, while terminal links consisted of 4 mins of exposure to response-independent deliveries of food and electric shocks. The rates at which these were delivered in the two terminal links were varied across the different conditions. Farley and Fantino assumed that food and shock delivery combine to influence choice in the following manner:

$$\frac{R_1}{R_1} = \frac{r_1 - cp_1}{r_2 - cp_2} \qquad (2.11)$$

The coefficient $\underline{c}$ functions to scale a single delivery of an electric shock in terms of a single food reinforcement. Its value will clearly depend on the parameters of the stimuli, deprivation states, etc. In the initial phase Farley and Fantino extracted $\underline{c}$ values for the two of three subjects whose results indicated conformity to matching. These values were then used successfully to predict initial link response ratios in a second phase where response and shock rates were again manipulated. Both subjects deviated slightly in the direction of undermatching.

Farley and Fantino's study clearly verifies an equation of the form of 2.11 where positive and aversive events are opposite in their effects but scalable so as to equate their magnitude. It is a better means of indicating the relative values of several alternatives than Equation 2.10, where the sum value of shocks and food reinforcements for each alternative is not computed. The approach adopted by Farley and Fantino could be extended as a general method of scaling value by means of the matching law.

2.4.6. Qualitative differences

Matching could be seen as a much more general phenomenon if it could be shown to be valid for choice between alternatives differing in the type of response required or the type of reinforcer scheduled. Demonstration of this requires evidence that biassed matching is an adequate description of behaviour under such circumstances. At least any deviations in the direction of undermatching or overmatching should be within the limits found when the alternatives involve the same response and reinforcer types.

Different reinforcers

If biassed matching were obtained for choice between two different reinforcers it would indicate that the values of one reinforcer of the first type could be expressed in units of the second type. For example, at certain parameter values of the two reinforcers, 1.0 ml of milk may be equal to 1.5 ml of sucrose solution. However, we may expect that for some combinations of reinforcers at least, matching may be violated because of basic interactions between the reinforcers (e.g. between alcohol consumption and cigarette smoking, Griffiths, Bigelow and Liebson, 1976). The finding of biassed matching with some combinations of qualitatively different reinforcers may help the identification of such basic or "biological" interactions.

Miller (1976) showed that three very similar reinforcers could be scaled in value by means of the matching law. Deliveries of two types of grains were arranged according to concurrent VI VI schedules. In three different sets of conditions subjects chose between hemp and buckwheat, wheat and buckwheat, and wheat and hemp, with varying relative rates of reinforcement across conditions. Matching of both time ratios and response ratios to reinforcement ratios was closely approximated for each pairwise comparison. In addition, bias values obtained in the first two sets of conditions could be used to predict the direction of preference for the hemp-wheat choice. These results clearly show that biassed matching can be obtained with qualitatively different reinforcers and that scales of reinforcer value may thereby be established.

Hollard and Davison (1971) programmed two concurrent VI schedules. One arranged deliveries of food, the other ectostriatal brain stimulation. In different conditions food reinforcement rate was varied while the rate of brain stimulation was held constant. For the three pigeons used, time ratios matched reinforcement ratios with consistent and pronounced bias toward food. Response ratios undermatched reinforcement ratios ($\underline{a} = 0.77$ for group data) with bias of approximately the same size as that found with time ratios.

Hall, Silverstein and Willis (1976) used two different reinforcers which would be expected to interact in a "biological" way: food and water. Two concurrent VI schedules arranged delivery of the different reinforcers. They presented group data only, which showed that both response ratios and time ratios strongly deviated from reinforcement ratios in the direction of undermatching ($\underline{a} = 0.52$ and 0.51, respectively). Both measures revealed a strong bias toward food. They suggested that matching is closely approximated when food is delivered less frequently than water, but not when it is more frequent. Confirmation of this hypothesis would help identification of the exact nature of the food-water interaction.

Quite different results to these were obtained in an experiment by Hursh (1978). Two monkeys were reinforced for lever pressing according to 3 concurrent VI schedules. Two of these schedules arranged presentation of food and the third arranged water presentation. In the first phase subjects earned their entire daily intake of food and water during experimental sessions, while in the second phase provisions were made for constant daily intake of the two commodities.

Results from both phases indicated that the distribution of both responses and time between the two food schedules undermatched the reinforcement distribution. The degree of undermatching was slightly greater in phase 1. In neither of the phases was the distribution of responses between the food and water schedules controlled by the relative rates of food and water reinforcement. In phase 1 the ratio of food to water responses increased as the rate of food delivery decreased. As a consequence of this change in the response distribution there was little variation in the ratio of food to water reinforcers. This ratio was also relatively constant in phase II, but in this case because of relatively unchanging response ratios.

Part of an experiment by Hamblin and Miller (1977) may also be mentioned here. Rats chose between sucrose and milk or between two different concentrations of sucrose arranged by two concurrent VI schedules. Unfortunately, the data from these two sets of choices were not separated, so that only overall results may be given. For all three subjects response ratios undermatched reinforcement ratios (a = 0.82, 0.85 and 0.86).

The results from experiments employing qualitatively different reinforcers show both that biassed matching may be obtained when the reinforcers are similar and that motivational interactions may result in strong deviations from matching. Thus matching is limited to choice between commodities which do not interact in this way. The exact limits of the applicability of the matching law, and how these are to be expressed, remain to be defined (but see Rachlin, Green, Kagel and Battalio, 1976, for one approach).

Different Responses

The adequacy of the matching law when the alternatives differ in the response required for reinforcement will be discussed in detail in Chapter 3. However two experiments will be briefly described here. In both of these studies the subjects were pigeons, the reinforcer food and the two responses key-pecking and treadle-pressing. From Wheatley and Engberg's (1978) data, consistent bias was revealed in fitting response ratios to reinforcement ratios, but not in the fit of time ratios to reinforcement ratios. Strong and consistent undermatching was found in both cases.

Davison and Ferguson's (1978) results similarly show bias as much stronger in response ratios than time ratios. In this experiment values of a extended over the range from strong undermatching to slight overmatching. In neither experiment were a values consistently greater or less when derived from response ratio or time ratio fits.

2.4.7. The Generality of Matching

This survey of the application of the matching law to behaviour generated by contingencies differing from those which provided the initial empirical base for matching has produced some contrasting conclusions. In some cases the variations result in little deviation from matching, whereas in others it is difficult not to conclude that some other equation best expresses the relations between response ratios and reinforcement ratios and between time ratios and reinforcement ratios.

Time matching certainly appears to be more general than response matching, and it is probably through assessment of deviation from this standard that we may best assess the boundary conditions of matching. Response matching seems highly dependent on particular local response rate patterns. For example, response matching is more likely with variable (VI, VR) rather than fixed (FI, FR) schedules where response rate is constant across time. Also, response matching seems particularly dependent on the post-changeover pattern of responding resulting from the use of a COD. Time matching is affected by these variables, but much less so than response matching.

It is therefore important that the particular local response rate patterns required for time and response matching be identified, and that associations between deviations of a particular kind and certain local response rate patterns be noted. To the extent that local response rate patterns can be identified with local reinforcement rate patterns we may then be able to predict whether matching will occur from consideration of the particular schedules and the changeover contingency. While the data are limited at present, it is hoped that the results to be presented in the ensuing chapters will aid such prediction.

There are, of course, other important variables. While there appears to be no reason for matching to be bounded by the use of any particular group of reinforcers, when there are basic interactions among the reinforcers employed matching is not able to describe the data. If consumption of one reinforcer affects the value of a second (as dry food consumption does the value of water) matching cannot be expected to describe the results. However, when such interactions are minimal, matching has been shown to be a worthwhile approach to the scaling of reinforcer value (e.g. Farley and Fantino, 1978 and Miller, 1976).

Many problems remain in the assessment of limits on matching but there is certainly enough evidence of its generality to consider attempts at solving them worthwhile. The simplicity of the matching law is sufficient justification for continued seeking of the conditions under which it holds.

2.5. OTHER MATCHING RELATIONS

2.5.1. Introduction

Up to this point we have only considered matching as a relation between relative response rate or relative time and relative reinforcement rate. But rate is only one parameter of reinforcement, and therefore not the only independent variable which may enter into a similar relation with time and response ratios. In this section we will consider several different proportions which may be substituted for relative reinforcement rate in Equation 1.1.

Two obvious parameters of reinforcement are magnitude and immediacy. These two variables have received much attention both in experiments concerned with matching, and in others designed simply to assess the effects of immediacy and magnitude of reinforcement on response rate. While reinforcement rate has been the predominant variable of interest with respect to matching, there is a reasonably large body of research which may be used to assess the validity of magnitude and immediacy matching. The approach adopted here will be similar to that in Section 2.3 where the empirical support for matching to relative reinforcement rate was assessed.

In the third subsection a relation similar to immediacy matching will be considered: that reinforced inter-response times (IRTs) are emitted in proportion to their relative reciprocal length. While IRT length is clearly not a parameter of reinforcement, it is a variable which can enter into a matching relation in the same way as reinforcement rate. Both for this reason and because of its relation to immediacy matching, this topic has been included in this section.

2.5.2. Magnitude Matching

Experiments designed to investigate magnitude matching typically arrange equal VI schedules of reinforcement. In different conditions the magnitude of one or both of the reinforcers is varied so as to obtain a range of relative magnitudes. The extent to which preference is explained by magnitude matching can then be assessed by means of the equation

$$\frac{R_1}{R_2} = d\left(\frac{m_1}{m_2}\right)^c \qquad (2.12)$$

where m_1 and m_2 are the magnitudes arranged by the two reinforcement schedules. As before, values of $\underline{c}$ and $\underline{d}$ are obtained by curve-fitting. The parameter $\underline{c}$ represents unaccounted for bias, and $\underline{d}$ deviations in the direction of overmatching or undermatching. Time ratios may be substituted for response ratios in the left-hand side of Equation 2.12.

Magnitude of reinforcement is commonly measured in one of two ways: either the duration of access to a reinforcing stimulus (e.g. 5 secs access to grain) or the actual amount delivered (e.g. 3 food pellets, 0.5 mg of a drug). The second of these methods has the advantage of precise specification of the magnitude actually obtained or consumed. When a pigeon is given access to grain for a certain period the proportion of that period actually spent eating is not usually measured. Whereas 5 secs may be programmed, time spent moving to the dispenser may reduce the amount of time spent eating to 4 secs. However, non-satiated animals will consume the exact number of food pellets delivered.

Some illustrative data

An experiment by Catania (1963b) provided the first evidence suggesting that relative response rates matched relative reinforcement magnitudes. Two equal concurrent VI schedules arranged delivery of reinforcers (access to grain) of varying durations. Response rate in an alternative was found to be a linear function, with zero intercept, of the magnitude of reinforcement provided in that alternative. It can be easily seen that Equation 2.12, with $c = 1.0$, follows from such a relation.

Brownstein (1971) replicated Brownstein and Pliskoff's (1968) experiment employing concurrent VT schedules, but varied duration rather than rate of reinforcement across the alternatives. For all three subjects used the proportion of time allocated to each alternative closely approximated the relative duration of access to grain arranged for that alternative.

Fantino (1973) reported an unpublished experiment by Fantino and Hursh in which two equal concurrent VI schedules arranged time-out from electric shock contingent on rats' bar-pressing. When the time-out durations programmed by each VI were equal, the proportion of responses made on each of the two bars was approximately 0.5. With a 60 secs duration programmed by one and 30 secs by the other, about 70% of responses were to the alternative associated with the longer duration. Although these results are far from conclusive, they suggest that magnitude matching could be extended to include reinforcers other than food.

Scheduled and obtained magnitudes

Three examples of experiments whose results seem consistent with Equation 2.12 have been briefly described above. They all share the assumption that the proportions of scheduled and obtained reinforcements are equal. However, if an organism allocates more time to or responds faster on one alternative then the obtained reinforcement rate is likely to be greater for that alternative. This would mean that there was a preference for one alternative not solely accountable in terms of relative magnitude.

Clearly, when magnitudes differ across alternatives we would expect the larger magnitude alternative to be allocated more time and responses. If there were a resultant reinforcement rate difference some of the preference shown would be due to the asymmetry in rate rather than magnitude of reinforcement. Such was the case in Brownstein's (1971) experiment where two of the three subjects obtained more reinforcers from the schedule associated with the longer reinforcement duration.

This difficulty may be circumvented by considering as the dependent variable total reinforcement magnitude: for each alternative the product of the magnitude of each reinforcement and the number of reinforcements (or reinforcement rate to give rate of reinforcement magnitude). Magnitude matching is then expressed by the equation

$$\frac{R_1}{R_2} = \frac{r_1 m_1}{r_2 m_2} \qquad (2.13)$$

This equation states that the ratio of response rates equals the ratio of total obtained reinforcement. As with Equation 2.12 a multiplicative coefficient, $\underline{d}$, and exponent, $\underline{c}$, may be added to give the generalized form of magnitude matching.

Unfortunately two of the experiments already described do not present data which allow reinterpretation in terms of Equation 2.13. However, a reanalysis of Brownstein's (1971) data serves to illustrate the effect of using obtained rather than scheduled reinforcement magnitudes. For the two subjects whose obtained reinforcement proportions differed substantially from 0.5, the data were converted to ratio form. Simple linear regression of log response ratio on log obtained magnitude ratio ($\log r_1m_1/r_2m_2$) and on log schedule magnitude ratio ($\log m_1/m_2$) was then performed using the data from both subjects. The values of the two parameters were $\underline{d} = 1.04$ and $\underline{c} = 0.75$ for the obtained magnitude regression (98% of the variance accounted for) and $\underline{d} = 1.07$ and $\underline{c} = 0.99$ for the scheduled magnitude regression (97%). Clearly there is a much stronger deviation in the direction of undermatching when obtained rather than scheduled magnitude is considered.

Consideration of scheduled rather than obtained reinforcement magnitudes may thus introduce a distortion: a greater preference is shown for the component arranging the reinforcements of larger magnitude than is due to the difference in scheduled magnitudes. The exponent $\underline{c}$ will be greater if the data is analysed in this way since scheduled magnitude ratios will be less extreme (closer to 1.0) than obtained magnitude ratios.

One means of ensuring that scheduled and obtained reinforcement rates are equal, and thus bypassing this difficulty, was first described by Stubbs and Pliskoff (1969). Instead of two VI schedules operating independently, one VI timer arranges reinforcements which are then randomly assigned to one or other alternative with a pre-specified probability. Once a reinforcer has been "set up" for either alternative it has to be delivered before another can be arranged. Consequently, unless one schedule has zero probability of reinforcement, the organism has to frequently switch between alternatives to obtain all scheduled reinforcements. Most of the experiments to be discussed below have employed the Stubbs and Pliskoff procedure because it allows examination of the effects of relative magnitude independent of any relative rate effects.

Experiments varying magnitude of reinforcement

In two experiments Walker and his co-workers varied relative duration of access to sucrose solutions. Rats' presses on two bars were reinforced according to a single VI schedule with equal probability of reinforcement for each alternative. Walker, Schnelle and Hurwitz (1970) used a COD of 2 secs, and found that for all subjects relative response rate undermatched relative duration of reinforcement. Walker and Hurwitz (1971) employed a 3 sec COD and again found undermatching in the results from all subjects. One reason for the undermatching may have been the relatively small COD durations employed. CODs of approximately 5 secs or more are usually required when using rats (Shull and Pliskoff, 1967).

Also in Walker et al's (1970) experiment, subjects were exposed to each condition for only 6 sessions. Since they gave no information on trends within each 6 session group, it is not clear whether the animals had fully adjusted to each new condition by the end of this relatively short period.

Fantino, Squires, Delbruck and Peterson (1972) used a procedure which is functionally the same as Stubbs and Pliskoff's. Two VI timers were concurrently programmed, but when either VI timer had set up a reinforcement, the other VI timer was halted. Both recommenced timing once the reinforcer had been delivered. The two alternatives were associated with two different durations of access to grain and relative reinforcement rate was varied across the different conditions. Baum's (1974a) reanalysis of their results showed both undermatching and overmatching of response ratios to total duration ratios amongst the different subjects used. The pigeons were consistent, however, in demonstrating a bias toward the component arranging reinforcements of shorter duration. This may be due to a factor discussed above: that the ratio of amounts eaten can differ from the duration ratio.

Deluty (1978) studied the effects of electric shock duration in a concurrent chains procedure. Rats responded on two VI initial links for access to food and electric shock. A single shock of fixed intensity was delivered at a certain time in each terminal link. Deluty tested the equation

$$\frac{R_1}{R_1+R_2} = \frac{d_2}{d_1+d_2} \qquad (2.14)$$

where d_1 and d_2 are the durations of shock in the respective terminal links. Rather than obeying this equation, all subjects deviated strongly in the direction of undermatching. Unfortunately, however, only a 2 sec COD was employed, and for most conditions length of exposure was only 5 sessions. Both factors can contribute to the likelihood of undermatching (de Villiers, 1977).

Both rate and magnitude of reinforcement have been manipulated in a number of experiments. In such instances the effects of these two reinforcement parameters may be considered independently by means of the equation

$$\frac{R_1}{R_2} = b\left(\frac{r_1}{r_2}\right)^a \left(\frac{m_1}{m_2}\right)^c \qquad (2.15)$$

The pigeons which served as subjects in an experiment by Schneider (1973) were exposed to twelve different conditions in which the alternatives differed in rate and/or magnitude of reinforcement. Reinforcements for pecking on the two keys were food pellets and were arranged according to a single VI schedule. Fitting Equation 2.15 to the data revealed strong undermatching: the value of $\underline{a}$ was 0.60 and of $\underline{c}$ 0.34. Magnitude of reinforcement seemed to exert relatively little influence over preference in this experiment.

Slightly different results were obtained by Hamblin and Miller (1977). One group of rats in this experiment chose between sucrose solutions of the same or different concentrations, while the other chose between milk and sucrose or equal concentrations of sucrose. All reinforcers were arranged according to two concurrent VI schedules.

Again strong undermatching was found, but the exponent for magnitude (c = 0.72) was larger than that for rate (a = 0.63). Considerable differences in procedure, reinforcers, subjects etc., make it impossible to give a reason for the difference between these results and those of Schneider (1973).

Todorov (1973) reinforced pigeons' key-pecks with access to grain according to two concurrent VI schedules. Both relative rate and relative duration of reinforcement were varied across different conditions. There was considerable inter-subject variation in the values of the parameters a and c but for all three subjects a was greater than c. The ranges were a: 0.5 to 1.4 and c: 0.2 to 0.5. One difficulty with this experiment is the fact that a 1 sec TO was used instead of a COD. The extent to which this influenced the results is not clear, but as noted in Section 2.4.2 matching occurs only as an artifact of particular TO values.

Some criticisms and illustrative experiments

The results described so far clearly indicate that response ratios undermatch magnitude ratios. However, the methods employed in a number of these experiments have already been criticised. In addition there are two other criticisms which apply to a range of these experiments and suggest caution in acceptance of their results.

The first of these is illustrated by the results of an experiment by Keller and Gollub (1977). Using two concurrent VI schedules both relative reinforcement rate and relative duration were varied across a number of conditions. Even with correction for actual rather than scheduled eating time relative response rates deviated strongly from relative obtained magnitude. The principal deviation was in the direction of undermatching. Keller and Gollub reasoned that the deviation may have been due to prolonged exposure of each pigeon to a range of relative reinforcement rates and durations. Accordingly, in a second phase each pigeon was exposed to only two concurrent VI VI schedules. For one, both equal reinforcement rates and equal durations were scheduled, while for the other there was an asymmetry in rate and/or duration of reinforcement. The schedules were designed to provide a variety of relative magnitudes across the seven different subjects. Grouping the results from all subjects showed that relative response rates very closely approximated relative obtained magnitudes. The number of conditions to which each subject is exposed thus appears to be an important factor, particularly, perhaps, when two variables are being manipulated across the different conditions.

A second criticism has been made by de Villiers (1977). He reported the results of an unpublished experiment by de Villiers and Balboni in which relative magnitude of reinforcement was varied in one set of conditions and relative rate in another. Reinforcements were arranged by a single VI schedule and probabilistically assigned to one of the two alternatives. COD duration was set at a value found to be optimal for matching in an initial phase of the experiment. Both response and time ratios closely approximated reinforcement rate ratios with $\underline{a}$ values of 0.89 and 0.94 for group data respectively. However both response and time ratios strongly undermatched magnitude ratios ($\underline{a}$ = 0.45 and 0.53 respectively).

The differences in the two sets of results could not be due to prolonged exposure effects (c.f. Keller and Gollub, 1977), since manipulations of relative reinforcement rate followed manipulations of relative reinforcer magnitude. Rather, de Villiers (1977) suggested that undermatching of response and time ratios to magnitude ratios is encouraged by use of the Stubbs and Pliskoff (1969) single VI procedure. When only magnitude is varied, half of the reinforcers must be obtained from the schedule arranging reinforcers of shorter magnitude. Thus a considerable amount of time must be allocated to this alternative simply to ensure that reinforcers of larger magnitude continue to be obtainable. This effect is magnified by the use of long CODs (7.5 secs in the de Villiers and Balboni study).

A comparison of the results of two studies, one using a single VI procedure and the other two concurrent VIs may be used in testing de Villiers' hypothesis. In most other respects, the procedures were the same in the two experiments. Iglauer and Woods (1974) reinforced two monkeys with intravenous cocaine injections according to two concurrent VI schedules. In different conditions the relative volume of the cocaine reinforcer was varied. Responding on a centre lever allowed access to two other levers, responses on which were reinforced according to the VI schedules. Reinforcement was followed by 5 mins of time-out (during which the drug could take effect) at the end of which the centre lever was available again. Changeovers between concurrent components initiated a 1.5 sec COD.

In a second experiment, Llewellyn, Iglauer and Woods (1977) used the same method with three monkeys but reinforcers were scheduled according to the Stubbs and Pliskoff (1969) procedure. The data were reanalysed, fitting response ratios to obtained intake ratios. Values of the parameters and the proportion of the variance accounted for by the line of best fit are shown in Table 2.4. The two subjects exposed to the above procedure in Iglauer and Woods study were Bernadette and Rico. Comparison of their results with those of Rico, Boris and Rodney in Llewellyn _et al_'s study does not reveal any significant difference in the values of _c_. Bias was much stronger in the latter study but the average degree of undermatching was approximately the same. The two other subjects in the Iglauer and Woods experiment (Willis and Boris) were exposed to the same basic procedure but with FR terminal links added. This had the effect of significantly increasing the value of _c_.

TABLE 2.4: Reanalysis of the data of Iglauer and Woods (1974) and Llewellyn _et al_ (1976).

Iglauer and Woods (1974)

Subject	d	c	r^2
Bernadette	1.06	.86	.93
Rico	.91	.88	.98
Willis	.90	1.49	.92
Boris	.79	1.11	.96

Llewellyn _et al_ (1976)

Subject	d	c	r^2
Rico	.69	.88	.62
Boris	1.41	.71	.86
Rodney	.61	1.01	.86

Thus, while the suggestion of de Villiers (1977) has an obvious logic, the data are not supportive. An experiment in which all subjects are exposed to both procedures may produce more favourable results. However, it must be noted that data from the Iglauer and Woods study were included in this reanalysis even if subjects showed almost exclusive preference for one alternative (response proportions of .01 or .99). de Villiers' (1977) reanalysis did not include these data and he found $\underline{c}$ values of 1.08 and 1.11 for Rico and Bernadette. This, of course, suggests that the different procedures do affect our conclusions about magnitude matching. Nevertheless, two of the three subjects in Llewellyn *et al*'s experiment exhibited behaviour which closely approximated magnitude matching.

While the data should be accepted with caution, the results from virtually all the experiments described indicate that response ratios undermatch magnitude ratios. In some instances the degree of undermatching was extreme (Todorov, 1973), but these experiments have been criticised for some shortcomings in the method employed. The most convincing evidence in support of magnitude matching comes from the second phase of Keller and Gollub's (1977) study. However, supporting evidence is needed to verify that response ratios match magnitude ratios when the subjects are not exposed to a long series of conditions.

2.5.3. Immediacy Matching

The third form of the matching relation concerns the effects on the distribution of responses and time between alternatives of a difference in the delay of reinforcement programmed for the two (or more) alternatives. If we define immediacy of reinforcement as the reciprocal of the delay value then matching is expressed by the relation

$$\frac{R_1}{R_2} = \frac{i_1}{i_2} \qquad (2.16)$$

where i_1 and i_2 are the immediacies for the respective alternatives. Two problems which arise in assessing the evidence for immediacy matching have already been discussed with reference to magnitude matching. The first is related to the fact that reinforcement rates may not be equal across alternatives. If they are not, then Equation 2.16 cannot be used to assess matching, and we must use an equation of the form

$$\frac{R_1}{R_2} = \frac{r_1 i_1}{r_2 i_2} \qquad (2.17)$$

The second problem, to be discussed below, concerns possible discrepancies between programmed and actual delays.

Delay of reinforcement in concurrent schedules

The data which provided the foundation for immediacy matching came from experiments by Chung (1965) and Chung and Herrnstein (1967). In both experiments pigeons were exposed to pairs of concurrent VI 1-min schedules with a COD of 1 sec throughout. Once a to-be-reinforced response had occurred the response keys were blacked out for the duration of the delay period during which the VI timers were halted. At the end of the delay period the reinforcer (access to grain) was delivered. Very little responding occurred during the black-out.

In Chung and Herrnstein's experiment one key was associated with a delay of 8 secs or 16 secs, while the delay for the other key was varied through the range 1 to 30 secs. Chung programmed reinforcement delays for one key only, but balanced the effects of blackouts <u>per se</u> by programming blackouts of equal duration for responses on the other key according to an independent VI 1-min schedule. Chung and Herrnstein analysed the data from both experiments, and concluded that response proportions matched immediacy proportions except for a degree of bias. For Chung's data, matching required that a 1.6 sec delay be assumed for responses on the key for which immediate reinforcement was programmed. This may be regarded as the actual time required for the pigeons to move from the key to the feeder.

Unfortunately fits of Equation 2.17 were not reported for the results of either experiment, and it is not clear whether relative reinforcement rates differed significantly from 0.5. Paralleling the case with magnitude matching, if reinforcement rates are ignored a greater preference is likely to be shown for the component associated with the smaller delay than is due solely to the difference in delays. Chung's data highlight a second difficulty in assessing immediacy matching: actual delays are likely to be longer than programmed delays by some constant. Since actual delays are very rarely measured we must usually rely on programmed values as approximations.

Three experiments by Herbert (1970) provide some additional data on immediacy matching. Pigeons pecks on each of two keys were reinforced with access to grain. A single VI schedule arranged reinforcements which were randomly assigned to the two alternatives with equal probability. In the first experiment blackouts of varying duration followed every response. Although relative response rate closely approximated relative immediacy of reinforcement, the results cannot be considered as confirmation of Equation 2.16 since relative immediacy was confounded with differential punishment (response-contingent time-out) across the alternatives. However the data are suggestive in the sense that matching to the combined effects of relative immediacy and relative punishment was obtained (c.f. Section 2.4.5).

Herbert's second experiment replicated one by Shimp (1969a) except that punishment was again confounded with reinforcement delay. In Shimp's experiment the first response after a VI timer had set up a reinforcement initiated a delay (black-out)period. The first response following termination of this delay period was reinforced. Under these conditions matching of relative response rate to the relative reciprocal of the delay periods was closely approximated. Shimp argued against Chung and Herrnstein's interpretation of immediacy matching in terms of delayed reinforcement effects on this basis.

Herbert's replication provided that every response except those reinforced initiated a black-out. For only one of the three pigeons did relative response rates approximate relative reciprocal of black-out duration. The results from the other subjects suggested indifference between the alternatives rather than matching. While Shimp's results suggest that the basis of immediacy matching is not in the decay of reinforcing effects with increasing response-reinforcer intervals, Herbert's data are more supportive of Chung and Herrnstein's hypothesis.

The third of Herbert's experiments replicated Chung's (1965). A black-out preceded reinforcement for pecks on one key, while black-outs were arranged at the same frequency for pecks on the other according to an independent VI schedule. Delay lengths were varied from 0.2 to 15 secs and were equal across the alternatives. The results from conditions in which delay length was in the range 3 to 15 secs were reanalysed assuming a delay of 1 sec on the "immediate reinforcement" alternative (c.f. Chung and Herrnstein's, 1967, assumption of a 1.6 sec delay). A fit of the equation

$$\log (R_1/R_2) = g \log (i_1 r_1/i_2/r_2) + \log h \qquad (2.18)$$

revealed slopes of 0.61, 0.61, and 0.40 for the three subjects. The proportions of variance accounted for were 74%, 92% and 78% respectively. The only explanation which may be suggested for the strong degree of undermatching is that Herbert employed the Stubbs and Pliskoff (1969) procedure for scheduling reinforcements. de Villiers' (1977) argument can be cited with respect to immediacy matching as well as magnitude matching.

The extant data are far from conclusive. The results of Herbert's third experiment contrast sharply with those Chung obtained using a very similar method. Also, Shimp's challenge to Chung and Herrnstein's interpretation of immediacy matching is not convincingly answered by Herbert's results. An alternative source of data will now be used in an attempt to resolve these issues.

Concurrent chains with FI or FT terminal links

Concurrent chains with VI initial links and FT terminal links are formally equivalent to concurrent VI schedules in which delays are imposed between responses and reinforcement. In practice there are two differences which should be noted: with concurrent chains CODs are often not employed and discriminative stimuli are used to indicate which of the FT schedules is in operation. The effects of this latter factor will be discussed below. However, we may examine the results from several experiments by Neuringer (1969) in which equal VI initial links and a COD were employed.

In Neuringer's first experiment pigeons' responses on two keys were reinforced according to independent VI 90 sec schedules by access to terminal links. Food was delivered in terminal links according to pairs of FI or FT schedules. One FI or FT value was constant at 10 secs while the other was either 2 secs or 20 secs. Relative initial link response rates undermatched relative terminal link immediacies, irrespective of whether the terminal links were FI or FT schedules. Although Neuringer did not report reinforcement proportions, a fit of Equation 2.18 would have produced the same conclusion, since more reinforcers would have been obtained from the smaller FI or FT component.

Deluty (1978) arranged concurrent chains with each terminal link consisting of intermittent delivery of food plus a single electric shock. The relative delays with which the shock followed entry into the terminal links were varied across different conditions. Like Neuringer, relative terminal link entries were not reported, but proportions of initial link responses undermatched delay proportions.

Another of Neuringer's (1969) experiments suggests reconsideration of Shimp's (1969a) results. Five pigeons were exposed to concurrent chains with the same initial links as above, but with one FTx terminal link and one chain FT x FR1 terminal link. The average proportion of initial link responses was 0.51. This indifference suggests that Shimp's requirement of a single response following a delay has approximately the same value as a simple delay before reinforcement. Thus it is the delay period itself which alters preference, not the temporal gap between reinforcement and the previous response. Chung and Herrnstein (1967) and Shimp (1969a) obtained similar results because they used delay contingencies (black-out and black-out plus a single response, respectively) of almost the same value.

Neuringer also showed that pigeons are almost indifferent to choice between FI and FT terminal links of the same duration. Thus we may look to the several experiments employing concurrent chains with pairs of FI terminal links for data on the effects of reinforcement delay.

Duncan and Fantino (1970) arranged two independent VI 1-min initial links with FI terminal links varying in duration from 4 to 60 secs. Relative initial link response rates showed extreme preference for the shorter FI terminal link. Unfortunately proportions of obtained reinforcements were not reported, prohibiting a reanalysis in terms of Equation 2.18.

In a similar experiment Killeen (1970) varied the duration of one FI terminal link over the range 5 to 60 secs while the duration of the other was constant at 20 secs. Preference for the shorter of the two FI terminal links was much more extreme than would be predicted by immediacy matching, even when reinforcement ratios are taken into account.

In two experiments Davison and Temple (1973, 1974) confirmed that response ratios overmatch immediacy ratios in concurrent chains with FI terminal links. A model was presented in the earlier experiment which showed a good fit to the data of Killeen (1970) and Duncan and Fantino (1970) by predicting such overmatching. Davison and Temple (1974) arranged choice between three FI terminal links. Their data were reanalysed by combining results from the second and third keys. Fitting Equation 2.18 revealed a slope of 1.45.

While results from the last four experiments described suggest that response ratios overmatch reinforcement ratios, data from Neuringer (1969) and from experiments employing concurrent VI schedules have shown deviations in the direction of undermatching. These contrasting findings may be partially explained by the results of an experiment by MacEwen (1972). Concurrent chains with VI initial links and FI terminal links were again employed. Through the different sets of conditions the ratio of the two FI durations was constant but their absolute sizes were varied. The pigeons' preference for the shorter of the two FIs increased as their absolute size increased. This result was confirmed by Williams and Fantino (1978).

Thus the slope obtained in fitting Equation 2.18 is dependent upon the absolute sizes of the immediacies. The smaller the immediacies (longer delays) the greater will be the slope.
One reason for the difference in results from concurrent schedules and concurrent chains is that the delays usually employed in conjunction with the former tend to be shorter than the FI durations in the terminal links of the latter. However Williams

and Fantino (1978) reanalysed Chung and Herrnstein's (1967) results. When data from conditions in which the constant delay on one key was 8 secs were considered separately from those in which it was 16 secs, it was clear that their results also showed increasing preference for the shorter delay as the absolute value of the delays increased.

One other factor may also have contributed to the difference in results obtained from concurrent schedules and concurrent chains. As mentioned above, discriminative stimuli are usually employed in concurrent chains to denote which of the FIs is in operation. Delay periods are simply denoted by black-outs in concurrent schedules. Navarick and Fantino (1976) found that preference for the shorter of two delays was more sensitive to variations in relative delay when there were discriminative stimuli associated with two FI terminal links than when the terminal links comprised black-out followed by reinforcement. Williams and Fantino (1978) found the same difference in sensitivity according to whether two FI terminal links were associated with the same or different stimulus conditions.

Conclusions

It is clear that immediacy matching fails as a means of predicting preference for different delays of reinforcement. Rather, we may conclude that there is a family of functions describing the relation between response ratios and immediacy ratios. The particular function obtained depends upon the absolute sizes of the delays used. Use of a relatively small range of immediacies to investigate choice leads only to erroneous conclusions about the effects of relative immediacy on relative response rate.

These findings may also serve as a warning against conclusive statements on rate or magnitude matching. It may be that the ranges of rates and magnitudes which have been employed are not large enough to attain a proper perspective. Rather, the results obtained with the range of values of these independent variables may have biassed our conclusions. Confirmation or refutation of this can only come with further experimentation.

2.5.4. Inter-Response Time Matching

Another matching relation is found when IRTs (inter-response times) are selectively reinforced. Although related to immediacy matching, research on this topic has a separate history and will therefore be discussed in this section. Virtually all of the research has been done by Shimp and his co-workers in a series of experiments which have clearly defined several boundary conditions of the phenomenon.

The relation to be considered is that the proportion of emitted IRTs of one class is equal to the relative reciprocal of the mean length of that class. This can be expressed as

$$\frac{R_1}{R_1+R_2} = \frac{1/t_1}{1/t_1+1/t_2} \qquad (2.19)$$

where R_1 and R_2 are the frequencies of the respective IRTs and t_1 and t_2 are the midpoints of the IRT classes. Thus if IRTs of length 2-3 secs and 4.5 - 5.5 secs are reinforced the expected proportion of IRTs falling in the smaller class is 0.67. Equation 2.19 can be expressed in ratio form and, as was the case with immediacy and magnitude matching, relative reinforcement rates must be taken into account.

Experiments by Shimp (1968) and Staddon (1968) established that relative frequencies of emitted IRTs covary in an orderly fashion with relative rate and duration of reinforcement. In Shimp's experiment two IRT classes were reinforced according to concurrent VI schedules and both relative rate and relative duration of reinforcement were varied across the different conditions. Response proportions tended to undermatch proportions of obtained magnitude of reinforcement. Staddon similarly reinforced two IRT classes: the smaller according to a VI schedule whose value was varied across the different conditions, and the larger on a continuous reinforcement schedule. Response ratios consistently undermatched reinforcement ratios.

Shimp (1969a) first provided an empirical base for Equation 2.19. In this experiment pigeons pecked a single key for food reinforcement. After each response the key was darkened until the beginning of the first IRT period during which it was red. After darkening again the key was green during the period of the longer IRT. Only responses occurring during red and green periods could be reinforced and only these were used in data analysis. A single VI schedule arranged reinforcements and these were assigned with equal probability to responses in red or green. In different conditions the sizes of the IRT classes were varied. The smallest was 1.43-2.43 secs and the largest 25.68-28.18 secs. The relative frequency of emission of an IRT closely approximated its relative harmonic length.

One limitation on IRT matching was demonstrated by Shimp (1970). Using a procedure similar to that described above, reinforced IRT classes were constant across the different conditions and the probability of a reinforcer being assigned to each class was equal. Variations in the overall reinforcement rate changed the distribution of responses between the red and green stimuli. Both overall response rate and the relative frequency of shorter IRTs increased sharply as reinforcement rate rose from 1 to 20 reinforcements per hour, reaching asymptotes at about 30 reinforcements per hour. Only the asymptotic response proportion matched the relative reciprocal of IRT length.

Results from an experiment by Hawkes and Shimp (1974) showed that IRT matching is also dependent upon the absolute sizes of the reinforced IRT classes. With constant overall reinforcement rate and relative IRT length, preference for the shorter class varied from indifference (when the lower bound of the shorter IRT class was 0.25 secs) to extreme preference (8.0 sec lower bound for shorter class). As the authors note, this finding parallels the dependence of immediacy matching on absolute values of the delays.

The results which have been obtained when responding is on one key only have been largely replicated with two key procedures. Moffitt and Shimp (1971) scheduled reinforcements for emission of the shorter IRT class on one key and the longer class on the second key, while Shimp (1971a) arranged reinforcements for two classes on one key and a third on the other. In both experiments relative response rate closely approximated relative reciprocal of IRT length, although there was a high degree of variability in Shimp's data.

Most of these experiments have also reported the extent to which relative response rates approximate relative reinforcement rate and/or magnitude when those factors are varied. The results reveal a tendency to undermatching, with consistent bias to the shorter IRT class.

Matching to relative reciprocal of IRT length is a phenomenon which is bounded by a well defined set of conditions (at least for pigeons pecking for food reinforcement). The similarity of several of the findings to those obtained in studies of immediacy matching is understandable considering the like nature of the respective procedures. As Hawkes and Shimp (1974) noted, schedules of IRT reinforcement are similar to concurrent chains with continuous-reinforcement initial links and FI, limited-hold terminal links. As the behaviour generated by a variety of other similar schedules is explored the two sets of data may come to be incorporated as the results of one class of contingencies.

2.6. MATCHING AND REINFORCEMENT RELATIVITY

Premack (1965, 1971) has formulated a concept of reinforcement in terms of the probabilities of the various behaviours in an organism's repertoire. Put simply, a more probable behaviour will reinforce a less probable one and a less probable one will punish a more probable one. The probabilities or values of a set of behaviours may be derived empirically by noting the relative amounts of time an organism allocates to each in an unconstrained situation. For example, if an organism spends four times as much time running as it does drinking when the two responses are freely available, making running contingent upon drinking will cause an increase in drinking rate, but running rate will decrease in frequency if drinking is contingent upon it. This formulation and some of the difficulties associated with it are discussed in more detail by Dunham (1977). There are close similarities between the concept of reinforcement embodied in the matching law and Premack's hypothesis (reinforcement relativity). These similarities have been explored in two different ways, to be discussed below.

Deriving matching from reinforcement relativity

Donahoe (1977) attempted a formalization of Premack's hypothesis which he applied to choice behaviour. He showed that the equation derived from the principle of reinforcement relativity predicts that relative time will match relative reinforcement rate. The assumptions required include symmetry of reinforcement type and magnitude and response type across the alternatives. In addition, the operant levels of the non-contingent responses must be equal and approximately zero.

Further, Donahoe showed the results of violating these last two assumptions. Bias is produced if the operant levels are not equal, while undermatching occurs because a high operant level response (e.g. wheel running) is used or because one or both of the reinforcers elicits the non-contingent response (this issue is discussed further in Chapter 5).

The derivation of the matching law from Premack's relational principle of reinforcement may aid the convergence of the two areas of research, both concerned with the topic of reinforcement. The predictions made by Donahoe remain to be tested, however. For example, there are no extant data which indicate whether operant level and degree of undermatching covary or not. One implication which does follow from an analysis of matching in terms of the relational principle is that allocated time may be a more appropriate metric than response rate. Such an argument has also been put forward by Baum and Rachlin (1969) and others. The use of time may be more critical when different response and reinforcement types are associated with each of the concurrent components (see Chapter 3).

Matching as a quantification of reinforcement relativity

In two papers Mazur (1975, 1977) has interrelated matching and reinforcement relativity in a different way: using the matching law as a means of quantifying the predictions made by the principle of reinforcement relativity. He measured time allocated to two different responses (running and drinking sucrose solution) when a certain amount of time engaging in one response was required for access to the second, and vice versa. Running was available until the rat had run for a certain time period, when the wheel was locked and the drinking tube became available. After a period drinking, running was again available, and so on.

Mazur assumed a general form of matching: the relative value of a response is equal to the amount of time allocated to it (see discussion of this in Section 2.8). For each of the subjects the relative values of running, drinking and other behaviours that it engaged in were assessed in an unconstrained situation. The following equation was then used to predict relative allocated times in the interdependent conditions described above:

$$\frac{T^{1}_{d+r}}{T^{1}_{d+r} + T^{1}_{o}} = \frac{pVd + (1-p)\ Vr}{pVd + (1-p)\ Vr + Vo} \qquad (2.20)$$

The subscripts d, r and o refer to drinking, running and other behaviours respectively, the V's are values as assessed in the unconstrained situation and the T's are times allocated in the interdependent conditions. p is the proportion of time required to be spent drinking of the total time spent drinking and running. Multiplication of the right-hand side of Equation 2.20 by p gives the predicted proportion of time spent drinking and by (1-p) the predicted proportion running.

Mazur (1975) showed the predictions of these equations to be fairly accurate under a variety of conditions associated with different values of p. Obtained durations tended to be slightly longer than those predicted however. In a second experiment Mazur (1977) obtained similar results, but showed that the accuracy of the predictions was partly dependent upon the absolute durations, with p constant. Significant deviations from the predictions were consistently found when very short durations were required (e.g. running durations of 1 sec). In another phase the values of drinking and running were shown to increase as less time was made available for their occurrence. Equation 2.20 is only able to make accurate predictions when the relative values of the behaviours remain constant.

Although certain limitations must be noted, Mazur's experiments demonstrate that the matching law may be used to make quantitative predictions where reinforcement relativity can only predict qualitatively. Use of the matching law in experiments concerned with reinforcement relativity will enable it to be tested under a much wider range of conditions than it previously has. Like Donahoe's work, this should enable a better assessment of the generality of matching.

2.7. THE NATURE OF MATCHING

Rachlin (1971) has argued that the matching law is not an empirical law which is subject to disproof. Rather, it formalizes our assumption that the only constraints an organism is under in a choice situation are the particular contingencies of reinforcement that we arrange. Thus, Rachlin sees the matching law as an empirical standard, deviations from which must be understood. If an animal is consistently deviating from matching we must manipulate its environment so that its behaviour conforms with the standard (e.g. by changing the COD, equalizing the force requirements on the manipulanda).

Rachlin's analysis may be attacked on several grounds. Firstly, while it is clear that adjustments to the experimental contingencies may be made so as to eliminate bias, undermatching and overmatching are not as easily dealt with. Given a large COD, the extant data give few clues to an experimenter wishing to transform undermatching into matching. In the case of immediacy matching, the results discussed in Section 2.5.3 suggest that whether we find undermatching, matching or overmatching will depend on the absolute values of the delays employed. It is clearly absurd to adopt the position that some delay values are right and others wrong.

Bias rather than undermatching or overmatching is obviously what Rachlin was referring to, since he stated "the matching law circumscribes our search for reinforcers in any situation". Undermatching describes an organism's behaviour when it is less sensitive to the contingencies than the matching law would predict. A search for reinforcers would lead us into trying to identify extra reinforcers for the operant response in the component arranging the lower reinforcement rate (or magnitude, etc.). Rachlin's position is only tenable if we are considering deviations which reflect bias rather than overmatching or undermatching.

Killeen (1972a) has criticised Rachlin's view, pointing out that his tautalogous matching law is not Herrnstein's (1961) equation but one of the form

$$\frac{T_1}{T_2} = \frac{V_1}{V_2} \qquad (2.21)$$

where V_1 and V_2 are the values of the two alternatives. Clearly value can only be determined empirically by noting relative times or relative response rates, so they add nothing to our understanding of behaviour. By contrast, Equation 1.1 makes a specific, empirically testable statement about the relation between response and reinforcement rate proportions. In fact, Myers and Myers (1977) have suggested that this form of the matching law is wrong, and that undermatching is the norm.

Rather than consider value, Killeen suggests the following equation as a model for choice behaviour:

$$\frac{T_1}{T_2} = \frac{f_1(r_1)}{f_1(r_2)} \quad \frac{f_2(m_2)}{f_2(m_2)} \quad \frac{f_3(i_1)}{f_3(i_2)} \quad \frac{f_4(x_1)}{f_4(x_1)} \qquad (2.22)$$

where the x's denote a parameter of reinforcement other than rate, magnitude or immediacy. This model assumes that the dimensions of reinforcement combine in a particular way to determine choice behaviour. Given this assumption, the task of experimenters is to define the nature of the functions f_1, f_2, f_3, and f_4.

In Section 2.4 a considerable body of evidence was discussed in order to evaluate Herrnstein's (1961) proposal that f_1 is the identity function. Similarly, in Sections 2.2 and 2.3 the nature of the functions f_2 and f_3 were considered. In each case it was clear that at least under some conditions the identity function was not appropriate. The other means of scaling the independent variables which was considered, power functions, proved satisfactory in a number of instances where identity functions failed. However the exact form of f_3 remains unclear.

The concept of value may be retained simply to denote a scale on which sets of contingencies may be placed. Calculation of scale positions requires assumptions about the nature of the functions f_i, amongst other things. For example, we may suggest that rate and magnitude of reinforcement combine multiplicatively while reinforcers and punishers must be algebraically combined to determine value. As Killeen (1972a) and Farley and Fantino (1978) have noted, the usefulness of the concept of value lies in the fact that scale positions should assume cross-situational generality.

2.8. MATCHING AND MAXIMIZING

Several authors have adopted an analytic rather than empirical approach to matching. They have endeavoured to show that matching is implied by the assumption that organisms will maximize reinforcement rate within the constraints of the contingencies. Such approaches assume either that maximizing is at the molar or at the molecular level of behaviour.

Maximizing at the molecular level

Matching of relative response rates to relative reinforcement rates is a molar phenomenon. Data which are used to verify or refute the relationship are averages over relatively long periods of exposure to the contingencies. Shimp (1966, 1969b) has argued that such averaging hides the molecular basis of matching. His thesis is based on a property of concurrent VI VI schedules: the more time a subject responds on one alternative, the greater the probability of reinforcement following a switch to the other alternative. Shimp suggested that at each point in time a subject will choose the alternative for which the momentary probability of reinforcement, weighted by its value, is greatest. Such an approach treats matching as derivative rather than fundamental.

Shimp's evidence comes from two sources. In an experiment employing discrete trials and contingencies similar to those found in concurrent VI schedules, Shimp (1966) showed that subjects' choices did correspond to changes in the probability of reinforcement for each component. Subjects switched when the probability of reinforcement was greater in the other alternative. Secondly, Shimp (1969b) showed by computer simulation that a subject responding to the alternative with the greater momentary reinforcement probability on a concurrent VI VI schedule will also exhibit matching. This conclusion has received further support from Staddon (1977b).

Shimp's analysis has been attacked on both empirical and logical grounds. The results of two experiments have suggested that matching can occur independently of maximizing. Again using discrete-trial analogues of concurrent VI VI schedules, Nevin (1969) and Herrnstein (unpublished, reported by de Villiers, 1977) failed to find correspondence between momentary probabilities of reinforcement and either changes in choice probabilities or post-reinforcement choices. However in both experiments relative response rates closely approximated relative reinforcement rates. The reason for the discrepancy between the results of these two experiments and Shimp's (1966) results is unclear, but it is obvious that momentary maximizing is not necessary for matching.

Herrnstein and Loveland (1975) have argued that momentary maximizing can be subsumed under matching. A response strategy which conforms to Shimp's principle can be seen as continuous choice between concurrent ratio schedules. Matching within each concurrent ratio pair is equivalent to momentary maximizing. Since matching does not always involve such strategies there is no conflict between matching and maximizing and no reason to regard maximizing as fundamental and matching as derivative.

Mazimizing at the molar level

While there are considerable difficulties associated with a molecular approach to maximizing, the assumption (or axiom, Herrnstein and Loveland, 1975) may be verified at the molar level. As Baum (1973a) has pointed out, regularities in behaviour often appear at the molar level, and matching is one of these. Two approaches have been made to discover whether molar maximizing is associated with matching.

Rachlin, Green, Kagel and Battalio (1976) used computer simulation to determine the distribution of time between two concurrent VI schedules which would maximize overall reinforcement rate. At all COD values this distribution was as described by time allocation matching. Thus matching may simply be a by-product of the organism maximizing the overall reinforcement rate. Unfortunately, Rachlin et al do not describe how total obtained reinforcement decreases with deviations from matching. In particular, it would be interesting to know the degree of deviation allowable before reinforcement rate decreases.

Staddon and Motheral (1978) used an analytic approach to show that if we assume a constant overall response rate (c.f. Herrnstein's 1970, parameter k: Section 2.9) matching can be derived from the principle of reinforcement maximization. A note of caution should be added, however, since the same approach failed to predict the behaviour generated by concurrent VI FR schedules, as revealed in Bacotti's (1977) data.

The fact that matching in concurrent VI schedules is associated with optimization of reinforcement rate gives reason to consider Equation 1.1 as a standard. Results which show considerable deviation from matching must be questioned because they violate our basic assumptions about behaviour. However, in order to understand such deviations we must understand the means by which organisms come to detect maximization, and for this we must return to detailed analyses of concurrent performances.

2.9. ABSOLUTE RESPONSE RATES

2.9.1. Herrnstein's Equations

It is clear that there are orderly relations between relative response rates and relative reinforcement rates. Such relations may be considered statements of the way in which one measure of response strength covaries with a parameter of reinforcement. Herrnstein (1970, 1974) has reasoned that if such regularity exists at the level of relative measures, order should also be found when absolute rates are considered. The search for a relation expressing the order must be circumscribed by the necessity of conformity to matching. Thus an equation relating absolute response rates to absolute rates of reinforcement must be shown to be in accord with Equation 2.1.

The Equations

One such relation, Equation 2.2, was proposed by Herrnstein (1961). It required a direct proportionality between response rate and reinforcement rate for each alternative. Responding in each component is independent of both the response and reinforcement rates of the other component. However a large number of experiments have shown an inverse relation between one component's response rate and the other's reinforcement rate. Thus, Herrnstein (1970) suggested the following pair of equations to account for absolute response rates

$$R_1 = \frac{k\ r_1}{r_1 + r_2 + r_e}$$

$$R_2 = \frac{k\ r_2}{r_1 + r_2 + r_e} \qquad (2.23)$$

with parameters k and r_e being measured in the same units as the response rate and reinforcement rates respectively. This equation expresses a proportionality between response rate and relative rather than absolute reinforcement rate. Note that Equation 2.23 implies that Equation 1.2 will be correct when total reinforcement rate is constant across the different conditions, as it was in Herrnstein's (1961) experiment.

Herrnstein (1974) has interpreted the parameter k as "the amount of behavior that the observed response would display if there were no source of reinforcement other than the one associated with the observed response". It is obvious from Equation 2.23 that if r_1 were the only reinforcement rate to be considered, $R_1 = k$. Thus k is the asymptotic rate of responding for the particular response under consideration. With multiple sources of reinforcement k is the total amount of behaviour, measured in units of the observed response. Its value is unaffected by changes in reinforcement. Rather, it characterizes the particular response under consideration.

The parameter r_e denotes the amount of reinforcement the organism obtains from sources outside those explicitly arranged. For example, activities such as grooming and sctatching have clear reinforcing value for the organism, and their rate is outside the control of the experimenter. In the usual environments in which we observe the effects of varying the parameters of reinforcement such extraneous sources are minimized. The denominator of the right-hand side of Equation 2.23 represents the total amount of reinforcement present in the situation.

It is clear that if $\underline{k}$ and r_e are the same for the two responses, matching follows from Equation 2.23. With concurrent schedules the total reinforcement context will be the same for both responses. Since $\underline{k}$ characterizes the particular response form, matching will follow as long as we have symmetry of response type across the alternatives.

Behaviour generated by simple VI schedules can be accounted for by an equation similar to 2.23. Here only one response is being explicitly reinforced so that we have

$$R = \frac{kr}{r + r_e} \qquad (2.24)$$

Because behaviour is always set in a context of other behaviours, each with its own source of reinforcement, the single schedule situation represents choice just as much as the concurrent schedule. This is succintly expressed in these equations.

Assessment of the equations

Herrnstein (1970) tested Equation 2.24 with data collected by Catania and Reynolds (1968). Six pigeons had been exposed to either four or six different VI schedules with reinforcement rates varying from 10 to 300 per hour. For three of the six subjects and for group data the proportion of variance accounted for by the equation exceeded 90%. The variety of parameter values obtained from the six birds' data suggests that values of <u>k</u> and r_e may be useful in characterizing inter-subject variability. The former indicates the maximum amount of responding that the organism is capable of, the latter the amount of reinforcement it obtains from extraneous sources.

Herrnstein used the results of Catania's (1963a) experiment to test Equation 2.23. In the first phase of this experiment overall reinforcement rate was constant, and relative rate varied while in the second reinforcement rate was constant for one alternative and varied on the other. With data from both parts combined, Equation 2.23 accounted for 91% and 90% of the variance in the two subjects' data.

Rachlin and Baum (1972) also assessed Equation 2.23, but in this case r_2 denoted the rate of delivery of non-contingent reinforcement. Subjects obtained food according to both a VI schedule for key-pecking and an independent VT schedule. Equation 2.23 was shown to generalize well to this situation.

Herrnstein's formulation accounts not only for the relation between response rate and reinforcement rate on single and concurrent VI schedules, but also for relations between a variety of measures of response strength and parameters of reinforcement. de Villiers and Herrnstein (1976) reviewed approximately forty experiments employing a range of species. Measures of response strength included response rate, latency to respond, running speed in an alley and swimming speed. The parameters of reinforcement varied were frequency, magnitude and immediacy of food reinforcement, magnitude of brain stimulation and immediacy of negative reinforcement. For both individual and group data, Equation 2.24 accounted for over 90% of the variance in at least 75% of cases. Neither exponential nor power functions proved to be better predictors of the behaviour.

What is surprising about these results is that such a simple equation could be so powerful a predictor. In particular, no rescaling of the independent variables was required to obtain good fits. de Villiers and Herrnstein suggested four reasons why this was so: (1) the ranges of the independent variables were relatively small; (2) experimenters tend to pick the more important parameters of reinforcement (e.g. concentration rather than viscosity of solutions); (3) no attempts have been made to modify reinforcement by manipulation of deprivation states; and (4) matching has been found with several of the independent variables used. Nevertheless, Herrnstein's account of absolute response rates has been shown to be a powerful analytic tool with great generality.

As mentioned above, a crucial question which must be answered is whether $\underline{k}$ is dependent only upon the response form itself. In particular, $\underline{k}$ must not vary with type or quantity of reinforcement or with deprivation state. de Villiers and Herrnstein (1976) analysed pertinent data from several studies, with equivocal results. While some experimental data supported the constancy of $\underline{k}$, in a few cases k varied substantially across different reinforcement conditions. Further experimentation involving strict control of response topography is needed to verify or refute the assumption.

In some instances the problem may be avoided by considering time allocated to a particular behaviour rather than its rate. This yields the equation

$$t = \frac{Tr}{r + r_e} \qquad (2.25)$$

where t is the amount of time allocated to the behaviour of interest and T is the total length of the period over which measurements are taken. Again, other parameters of reinforcement may be substituted for rate, or value may be used as a shorthand means of denoting the combined effects of these variables. One difficulty associated with the use of time allocation is the means by which exact measurements can be taken. With only one response of interest the experimenter is required to determine when the subject is exhibiting the response and when not. Measurement by observation will therefore be required. While use of time allocation avoids the problem of the constancy of k, the potential difficulties involved in taking exact measurements will be a strong drawback in some instances.

2.9.2. Alternatives to Herrnstein's Equation

Several alternative formulations of the effects of reinforcement on absolute response rates have been proposed. Most embody assumptions similar to Herrnstein's, but with slightly different mathematical forms and implications. We will firstly consider a precursor of Equation 2.25.

Catania (1963a, 1966, 1969) suggested the following relation between response rates and reinforcements rates in concurrent schedules:

$$R_1 = \frac{k\ r_1}{(r_1+r_2)^n} \tag{2.26}$$

where the value of the parameter n is slightly less than 1.0. Herrnstein (1964) had disagreed with Catania in suggesting that n = 1.0. In both cases response rate is proportional to reinforcement rate and inversely related to reinforcement from other sources. No account was taken of unprogrammed reinforcement, but this value is usually small in concurrent VI schedules.

However, Catania (1969) proposed that the reduction in rate of one response produced by an increase in the rate at which a second response is reinforced is due to an inhibitory process. That is, reinforcement of a response inhibits the rate of all other responses. Catania (1973) extended this concept in arguing that each reinforcer has an inhibitory effect on all behaviour, while its excitatory effect is specific to responses in the same class as the response that produced it.

Using these assumptions Catania was able to derive a quantitative account. He suggested that the excitatory effect of reinforcement $f(r_1)$, is linearly related to its rate, thus

$$f(r_1) = Kr_1 \tag{2.27}$$

Similarly the inhibitory function g, of all reinforcers Σr, can be expressed

$$g(\Sigma r) = \frac{C}{C + \Sigma r} \tag{2.28}$$

where the value of C depends upon the magnitude of the inhibitory effect. Multiplying these two equations together and setting KC = k we obtain

$$R_1 = \frac{kr_1}{C + \Sigma r} \tag{2.29}$$

When there are two programmed sources of reinforcement so that $\Sigma r = r_1 + r_2$ this equation is mathematically equivalent to Equation 2.23, with $C = r_e$. Clearly both equations will make similar predictions about concurrent performances, particularly with regard to matching.

Staddon (1977b) showed that two other sets of assumptions could be used to derive equations similar to Herrnstein's. Firstly, he assumed that the effect of reinforcement is simply to inhibit all behaviour except those responses in the same class as the reinforced response (c.f. Staddon and Simmelhag, 1971). By also making the assumptions that rate of responding is proportional to momentary probability of reinforcement and that the probabilities of responding and not responding sum to zero, he was able to derive Herrnstein's equation for absolute rates of responding.

The second set of assumptions and associated analysis was discussed in Section 2.8 as an attempt to formalize the momentary maximizing hypothesis. The two principle assumptions were that an animal does not respond unless the probability that a reinforcement has been set up exceeds a certain value, and that there is a constant ceiling on response rate. An equation similar to Equation 2.26 was derived using these assumptions.

Both the second of the equations derived by Staddon, and Catania's (1973) equation imply a proportionality between Herrnstein's parameters k and r_e. Evidence which supports or refutes this contention may be used to separate the various formulations. Some such data were described by Staddon, and although they were generally consistent with the proposal that k and r_e are correlated, they cannot be regarded as definitive.

Another alternative to Equation 2.23 was proposed by Davison and Hunter (1976). This is simply a modification to that equation which provides a basis for undermatching or overmatching in the function relating absolute response rates to reinforcement rates. It can be expressed

$$R_1 = k^1 \left(\frac{r_1}{r_1 + r_2 + r_e} \right)^a \qquad (2.30a)$$

$$R_2 = k^1 \left(\frac{r_2}{r_1 + r_2 + r_e} \right)^a \qquad (2.30b)$$

The value of a obtained by fitting this pair of equations should be the same as that obtained using Equation 2.2. Some evidence in support of this contention was presented by Davison and Hunter. However such a modification of Herrnstein's equation does not lead us any further toward understanding the antecedents of deviations from matching and can serve a descriptive purpose only.

The fact that several different approaches to an understanding of the relation between absolute response rates and reinforcement rates have converged on similar equations adds weight to Herrnstein's original formulation. However, several difficult problems remain. In particular, the issues of the constancy of k and the degree of correlation between k and r_e have yet to be resolved. These difficulties present a barrier both to a more complete understanding and to the extension of Herrnstein's equations to behaviour generated by other schedules of reinforcement (e.g. see Timberlake, 1977, for a discussion of the application of Herrnstein's equations to ratio schedules).

2.10. MULTIPLE SCHEDULE PERFORMANCE

Matching provides a reasonable description of behaviour when two alternative sources of reinforcement are simultaneously available. However we would expect to find a similar relationship between relative response rates and relative reinforcement rates when the sources are made available successively. Herrnstein (1970) has extended his analysis to include multiple schedule performance.

Research on this topic has centred on a phenomenon termed behavioural contrast by Reynolds (1961a). This will be discussed in detail in Chapter 6, while we will be concerned here with an appraisal of the success of Herrnstein's approach. Briefly, when one component of a multiple VI VI schedule was changed to extinction, Reynolds found that response rate in the other (unchanged) component rose. Clearly such a result is consistent with the principle expressed by Equation 2.23: the rate of a response will increase when its relative reinforcement rate increases.

Results from further experiments (Reynolds, 1961b,c,d, 1963) suggested that the important variable for the production of a contrast effect was the reduction in reinforcement rate rather than response rate in the changed component. Such support indicated that an equation similar to Equation 2.23 may account for contrast effects in multiple schedules.

Herrnstein's equation

The effects of variations in relative reinforcement rate on relative response rate are considerably smaller in multiple schedules than concurrent schedules. Herrnstein (1970) suggested that this was because of the (usually) less rapid changes from one component to the other, and the presence of discriminative stimuli. Thus, in multiple schedules there is a lesser degree of interaction between response rate in one component and reinforcement rate in the other. Mathematically, the simplest way of expressing this is by the equations

$$R_1 = \frac{kr_1}{r_1 + mr_2 + r_e} \qquad (2.31)$$

$$R_2 = \frac{kr_2}{mr_1 + r_2 + r_e}$$

where $0 \leqslant m \leqslant 1$. As the degree of interaction between components is increased (by reducing component duration) m will increase. Concurrent schedule performance may be considered a special case with $m = 1.0$.

This formalization of Reynolds' analysis has been tested on some extant data. Herrnstein (1970) used the results from experiments by Lander and Irwin (1968), Nevin (1968, 1974) and Rachlin and Baum (1969). In each of these one VI component was constant while the value of the other was varied, and in each case a good fit was obtained. de Villiers (1977) reported fits of Equation 2.31 to data from Reynolds' (1963) experiment and one by de Villiers (1972) which employed multiple RI RI schedules of shock avoidance. Values of m varied over the range 0.1 to 0.5 for these experiments.

Equation 2.31 may be used to describe how the ratio of response rates varies with changes in the two reinforcement rates of a multiple schedule:

$$\frac{R_1}{R_2} = \frac{r_1}{r_2}\left(\frac{mr_1 + r_2 + r_e}{r_1 + mr_2 + r_e}\right) \qquad (2.32)$$

As before, we are assuming that the degree of interaction is the same whichever direction of influence is considered, and that the amount of reinforcement the organism obtains from unprogrammed sources (r_e) is the same whichever component is in operation. A plot of Equation 2.32 shows that response ratios undermatch reinforcement ratios unless $m = 1.0$. The degree of undermatching is inversely related to the size of m. Herrnstein (1970) showed that Reynolds' (1963) data was well described by a relative rate version of this equation.

The interpretation of m

The status of Equations 2.31 and 2.32 as accounts of multiple schedule performance depends principally upon whether m truly represents the degree of interaction between response rates in one component and reinforcement rates in the other. This can be easily tested by seeing whether the value of m, as determined by some curve-fitting procedure, covaries with component length. Alternatively, we may note whether matching is more closely approximated as component length decreases.

Both Shimp and Wheatley (1971) and Todorov (1972) adopted the second approach and obtained similar results. Shimp and Wheatley varied component duration over the range 2 - 180 secs and found that matching was most closely approximated with 5 sec components. As component duration increased beyond 5 secs the degree of undermatching also increased. Todorov used components of 5 - 30 secs length. Matching was most closely approximated with 10 sec components, and the greatest deviation was observed with the longer component durations. Notably, in both experiments matching was not most closely approximated when component duration was lowest. This suggests that m may equal 1.0 at some critical duration and decrease as duration deviates on either side of this value.

Menlove (1975), using component durations of 5 and 180 secs, found greater deviation from matching with the larger duration. In addition, Menlove showed that with the 5 sec components local patterns of responding were more like those observed in concurrent schedules, but with 180 sec components they were typical of multiple schedule patterns. Further research may reveal that m also reflects the pattern of responding, while both are dependent upon component duration.

de Villiers (1974) verified the relation between $\underline{m}$ and the degree of undermatching using rats responding on multiple VI VI schedules of shock avoidance. With unequal VI schedules component duration was varied over the range 13.3 secs - 6 mins. Matching of relative response rate to relative reduction in shock frequency was closely approximated at the lowest durations of 13.3 and 40 secs. The degree of deviation increased as component length was increased beyond these values.

Both de Villiers and Shimp and Wheatley varied relative reinforcement rate with component durations set at values at which matching had been closely approximated (5 secs and 40 secs respectively). In neither case was any consistent deviation from matching revealed, suggesting that $\underline{m}$ was very close to 1.0 with these durations. It therefore seems as though the value of $\underline{m}$ accurately reflects the degree of interaction in multiple schedules. As this is decreased by lengthening component duration the degree of undermatching increases.

However, Edmon (1978) has demonstrated that in one respect the data of Shimp and Wheatley (1971) and Todorov (1972) do not support Herrnstein's formulation. Equation 2.31 predicts that absolute response rate in each component should decrease as $\underline{m}$ increases. Edmon's reanalysis of the data from these two experiments showed that as component duration decreased, response rate in the richer component increased, while it was approximately constant in the less lucrative component. Thus, while relative response rate changed in conformity with Equation 2.32 this was not due to absolute response rates following the prediction of Equation 2.31. This finding is difficult to understand in terms of Herrnstein's formulation, and indeed any other account of multiple schedule performance (see Chapter 5).

Other tests of Herrnstein's equation

Herrnstein and Loveland (1974) considered another implication of Equation 2.32: the smaller the values of $(r_1 + mr_2)$ and $(mr_1 + r_2)$ relative to the value of r_e, the more closely should matching be approximated. They manipulated these relative values by changing the animals' deprivation level (the less deprived the animals the greater the value of r_e relative to the values of r_1 and r_2). Using a VI 2-min VI 4-min schedule with 2 min components, pigeons' body weights were varied from 80% to 110% of their free-feeding weights. For all five pigeons relative response rate matched relative reinforcement rate at either 100% or 110% of free-feeding weight.

Nevin (1974) explicitly introduced an alternative source of reinforcement. Components of the multiple schedule alternated with a black-out period during which non-contingent reinforcement was delivered. By the same logic which predicted Herrnstein and Loveland's result, it is clear that matching should be more closely approximated as rate of reinforcement in the black-out increases. Herrnstein (1970) analysed the data (prior to its publication) and showed that this was the case: relative response rate changed from indifference (0.50) to within 0.03 of relative reinforcement rate as black-out rate increased.

Two predictions of Equation 2.31 were tested by Spealman and Gollub (1974). They generated these predictions in the following way. With equal VI components in a multiple VI VI schedule response rate in the first component will be

$$R_1 = \frac{kr_1}{r_1 + mr_1 + r_e} \qquad (2.33)$$

If the second component is then changed to extinction, response rate in the first component becomes

$$R_1{}^1 = \frac{kr_1}{r_1 + r_e} \qquad (2.34)$$

Thus the relative increase in response rate in the unchanged component is given by

$$\frac{R_1{}^1 - R_1}{R_1} = \frac{mr_1}{r_1 + r_e} \qquad (2.35)$$

This equation implies that with m and r_e constant, the magnitude of behavioural contrast is greater, the larger the value of r_1. However Spealman and Gollub showed the opposite to be the case: the magnitude of the contrast effect was smaller with lower reinforcement frequencies. Even if the parameters are not constant, the prediction of Equation 2.35 is the same, since increasing r_1 is likely to decrease r_e, and perhaps increase m.

These same equations may be used to make a second testable prediction. R_1 represents response rate in one component of a multiple VIx VIx schedule, while $R_1{}^1$ may be considered the response rate in a single VIx schedule. Clearly, $R_1{}^1 > R$ if $m > 0$, and r_e is the same in both cases. Thus, response rate should be greater on a simple VI schedule arranging the same reinforcement rate as a multiple VI VI schedule. Results from several experiments have supported this prediction: Herrnstein (1970) cited unpublished data collected by Terrace, and de Villiers (1974) arrived at the same conclusion from experiments on rats reinforced by shock avoidance. However Spealman and Gollub's data indicated that response rates were higher in the multiple schedule. The reason for this discrepancy is unclear, but may be related to whether the value of r_e is different for the two schedule types. Certain procedures may encourage such variation more than others.

<u>Aversive properties of extinction</u>

One other difficulty, described by Herrnstein (1970), arises when a slightly different procedure is used to demonstrate contrast. This was first described by Terrace (1966). If animals responding on a single VIx schedule are then exposed to a multiple VIx EXT schedule, response rate is higher in the VI component of the multiple schedule than in the single VI schedule. However, Equation 2.34 describes response rate for both. Herrnstein (1970) suggested that this change in response rate may be due to the aversive properties of extinction, so that response rate in the VI component of a multiple VI EXT schedule is properly

$$R_1^{11} = \frac{kr_1}{r_1 - r_2 + r_e} \qquad (2.36)$$

where $-r_2$ represents this aversive aspect in negative units of reinforcement rate. Clearly, response rate will then be greater in the VI component of the multiple schedule than in the single VI.

Some evidence is available to support the fact that EXT components of multiple schedules are aversive. Rilling, Askew, Ahlskog and Kramer (1969) allowed subjects to escape from either component of a multiple schedule by responding on a particular key. They demonstrated that pigeons will respond to escape from the stimulus signalling the lower rate of reinforcement. The rate of escape responding was greater when the lower valued component was extinction than when it was the VI 5-min component of multiple VI 30-secs VI 5-min. The responding was to some extent dependent upon the alternation of the high valued component with the low valued one. Thus, Herrnstein's explanation in terms of the aversive properties of extinction is supported by the available data, but the problem of measurement of this aversiveness remains.

Conclusions

Herrnstein's equations have been shown to provide a good account of multiple schedule performance within a limited range of conditions. This is despite the fact that matching occurs in different ways in multiple and concurrent schedules, as Rachlin (1973) has pointed out. In concurrent schedules the organism is free to allocate time between alternatives whereas in multiple schedules the organism can only adjust response rate within components. That is, matching results from the adjustment of the proportion of time allocated to responding and the proportion to other behaviour within each component. Difficulties associated with Herrnstein's approach are met in moving outside the range of conditions considered so far. These will be discussed in Chapter 4.

2.11. THE RESEARCH

This review of research on the matching law has been exhaustive rather than selective. Not every topic discussed can be related directly to the experiments to be reported in subsequent chapters. However, in any area of research many interrelations exist between the topics which comprise it, and a particular empirical finding has indirect ramifications as well as the obvious implications for which it was designed.

The experiments discussed below are aimed principally at establishing or verifying some boundary conditions of matching. This was the subject matter of Section 2.4. Here we will be concerned with expanding our understanding of these limits.

In Chapter 3 experiments will be reported which consider the extent to which biassed matching is sufficient to account for concurrent performances when the alternatives differ in the type of response required for reinforcement. This matter has been discussed briefly in Section 2.4.6. A further issue which will be examined is whether the bias values obtained are independent of the type of reinforcer used. The results will thus have implications for the matter of the constancy of Herrnstein's paramater $\underline{k}$, as discussed in Section 2.9.1.

The COR will be considered as an alternative to the COD in Chapter 4. In addition to its effects on matching, general properties of the COR will be reported so as to establish some basis for understanding its role in concurrent performances. The restriction on the generality of matching imposed by the need to employ a COD of appropriate size was discussed in Section 2.4.2. Exploring an alternative is one means of extending the generality of matching, or at least gaining a better understanding of why a COD must be employed.

Unlike the experiments described above, those in Chapter 5 will be concerned with multiple schedule performance. The topic of interest here will be recent evidence which has suggested that under some conditions behavioural contrast may be due, at least in part, to reflexive rather than operant responding. Such behaviour is obviously outside the purview of the matching law. This evidence will be evaluated and further investigations carried out. The implications of this hypothesis extend to the limiting conditions of both multiple and concurrent schedule performance. Because multiple schedules are easier to use in investigations of this hypothesis, they will be employed here.

In the final experimental chapter some ideas emerging from the research in Chapter 5 will be extended. In particular, a suggestion will be made as to how Herrnstein's equation for absolute response rates may be modified so as to account for patterns of local response rate, as exemplified by FI performance. This approach may be valuable in gaining a better understanding of some aspects of multiple schedule performance.

One important theme through all this work is the concern with local response rates. In Section 2.4.3. mention was made of how local response rates often differ in a systematic way between components of concurrent schedules. For example, responding is often faster to the less lucrative alternative of two concurrent VI schedules. In each of Chapters 3, 4 and 5 factors which influence this difference will be the topics of the research and discussion, while in Chapter 6 the patterns underlying such local response rate differences will be discussed.

CHAPTER 3

CONCURRENT PERFORMANCES WITH DIFFERENT RESPONSE REQUIREMENTS

3.1. INTRODUCTION

The two experiments in this chapter will be concerned with several issues which are critical to the generality of matching. Both address the problem of whether biassed matching is sufficient to account for concurrent performances when the alternatives differ in the response form required for reinforcement. Several possible outcomes of varying relative reinforcement rate in such a situation can be considered. Firstly, bias may be the only systematic deviation from matching. Such a parsimonious result would extend the generality of matching considerably, and enable scales of preference for different responses to be established (c.f. Miller, 1976, and Section 2.4).

Secondly, bias values may reveal minor or unsystematic preferences, but with strong deviations from matching of another kind. The third possibility is that both bias and other deviations may be systematic. In this case, bias may be considered to reflect preference for one response over another, with undermatching or overmatching appearing characteristic of concurrent performances with different response topographies. These last two cases comprise the ways in which matching may be violated. However, the second of these retains some of the implications of Herrnstein's account, since preference is reflected in the bias parameter, and the possibility of scaling is preserved.

In the second experiment a further issue will be examined: whether preference for one response over another is affected by the particular reinforcer used. As long as preference is reflected in part by the bias parameter, we can see if the degree of preference varies according to the nature of the reinforcer maintaining the two types of responding. If reinforcer type has an effect, then scales of response preference will be different for each type of reinforcer. Intransitivity of response preference with respect to reinforcer type would clearly limit the utility of such scaling. In addition, the degree of undermatching or overmatching may vary with reinforcer type, making statements about relative preferences more complex.

3.2. EXPERIMENT 1

In Section 2.4.6 some experiments were described in which qualitatively different reinforcers were associated with the two alternatives of a concurrent schedule. The review of the results of these experiments suggested that biassed matching provides a good description as long as the reinforcers are not too dissimilar and no motivational interactions are involved. Since this latter factor is irrelevant when we consider choice between responses of different topography, we might reasonably expect biassed matching to be sufficient to account for the distributions of time and responses in such situations.

Indeed, this is implied by Herrnstein's (1970) equation for absolute response rates, and his interpretation of the parameter *k* (Herrnstein, 1970, 1974). For two concurrent

VI schedules we have the pair of equations

$$R_1 = \frac{k_1 r_1}{r_1 + r_2 + r_e} \qquad (3.1)$$

$$R_2 = \frac{k_2 r_2}{r_1 + r_2 + r_e}$$

and therefore

$$\frac{R_1}{R_2} = \frac{k_1}{K_2} \; \frac{r_1}{r_2} \qquad (3.2)$$

According to this analysis, the difference in response requirements across the alternatives should be reflected as biassed matching when relative reinforcement rate is varied. Thus, the rate of any response can be rescaled in units of the rate of another by use of a simple multiplicative coefficient. Note that $\underline{k}$ is the only parameter which can reflect the difference in the two responses, since r_e is part of the total reinforcement context and therefore common to both alternatives. Herrnstein (1974) has interpreted $\underline{k}$ as the asymptote of the rate of the response in question.

However, the results of experiments by Wheatley and Engberg (1978) and Davison and Ferguson (1978), discussed in Section 2.4.6, suggested that a greater degree of undermatching may be found when choice is between different response topographies than when there is symmetry of response form. The degree of undermatching was approximately the same whether time or response ratios were fitted to reinforcement ratios. This contrasts with the results of most experiments in which a COD is employed, where undermatching is stronger for response ratios (see Section 2.4.3). Preference for one response over the other was revealed in the values of the bias parameter obtained from both time ratio and response ratio fitting. In both experiments more extreme preference was shown in the allocation of responses than in time allocation. These results suggest that local response rate was faster for the more preferred response, but independent of relative reinforcement rate.

Some additional data which may clarify these findings are presented in this experiment. Rats rather than pigeons were used and the responses were bar-pressing and chain-pulling. The use of a different species and different response types may help to establish whether the finding of the two experiments mentioned above are general to concurrent performances with different required topographies. If this is the case, some doubt must be cast on the ability of Equation 3.1 and 3.2 to account for such performances.

Method

Subjects. Two male Wistar hooded rats, experimentally naive and approximately 6 months old at the start of the experiment served as subjects. They were allowed access to food for 1 hour after the end of each session, with free access to water. Housing was in individual cages in a temperature and humidity controlled room with a 12-hour day/12-hour night cycle.

Apparatus. The experimental chamber measured 22 cm x 22 cm x 21 cm high. A 5 cm long bar, which could be operated by a force of 0.10 N, protruded 1 cm into the chamber. This was situated in the middle of one panel and below it was a food magazine into which 45 mg food pellets could be deposited. A 14 cm stainless-steel chain supporting a 2.3 cm diameter ring hung from the ceiling 10 cm from the bar. This could be operated by a downward force of 0.26 N. The chamber, together with a buzzer and a white noise generator for masking external sounds, was enclosed in a sound resistant shell with an exhaust fan in one wall. Control of the experiment and recording of data were performed by a PDP-11 computer.

Procedure

Each animal was exposed to a continuous reinforcement schedule on each manipulandum until at least 100 responses had been made. For each manipulandum a further session of VI 2-min reinforcement was programmed.

Following preliminary training subjects were run on the schedules indicated for the number of sessions indicated in Table 3.1. These were all concurrent VI VI schedules with a 5 sec COD. The intervals comprising each schedule were determined using Catania and Reynolds' (1968) formula with N=10. The first VI schedule in each pair arranged reinforcements for chain-pulling and the second for bar-pressing. Houselights were on for the duration of each session (60 min) and reinforcement was signalled by a 0.5 sec buzz. Sessions were run seven days per week.

Time allocated to each alternative was recorded from the first response after a changeover until the first response (on the other manipulandum) after the next changeover. Termination of exposure to each schedule occurred when, for each alternative, response rate and allocated time showed no consistent directional change over 3 consecutive sessions, with a minimum of 5 sessions for each schedule.

Coefficients of variation for the response and time proportions calculated over the last three sessions of each condition did not exceed 0.18 for R51 and 0.17 for R52.

TABLE 3.1: Sequence of schedules, number of sessions of exposure, response rates, allocated time and reinforcement rates.

	VI Schedule (sec)			Responses per min		Time (min)		Reinforcements per hour	
Subject	chain	bar	Sessions	chain	bar	chain	bar	chain	bar
R51	120	120	7	3.13	32.2	36.6	143.4	13.7	30.0
	180	90	7	2.71	33.4	26.1	153.9	13.7	25.7
	240	80	13	2.51	33.7	18.7	161.3	10.0	49.0
	300	75	14	2.85	27.9	23.1	156.9	10.0	47.3
	120	120	7	5.58	26.2	39.1	140.8	23.7	31.0
	90	180	13	8.91	22.3	62.6	117.4	31.7	17.7
	80	240	17	12.5	16.6	78.7	101.3	44.7	13.3
	75	300	23	14.7	13.9	82.4	97.6	45.7	10.0
	780	65	8	2.06	35.5	13.3	166.7	3.33	56.3
	65	780	16	17.9	7.07	126.9	53.1	54.3	4.00
R52	120	120	7	5.27	14.8	53.5	126.4	24.3	29.0
	90	180	8	5.94	14.8	55.6	124.2	31.7	17.7
	80	240	12	9.88	9.34	76.6	103.4	44.3	13.0
	75	300	7	8.43	8.79	89.4	90.6	45.3	10.0
	120	120	7	4.42	16.14	51.1	128.9	27.0	29.0
	180	90	9	3.89	14.44	43.4	136.6	17.0	35.0
	240	80	7	3.03	27.7	27.7	152.3	12.3	45.7
	300	75	7	2.97	38.9	31.7	148.3	10.0	46.0
	65	780	16	11.69	8.67	113.7	66.3	54.3	4.00
	780	65	7	1.81	33.6	19.0	161.0	4.0	54.0

Results

Sums over the last three days of each condition were used to calculate response rates, allocated time and reinforcement rates, all of which are shown in Table 3.1. It is clear that while the rate of reinforcement for bar-pressing closely approximated the scheduled rate, substantially fewer reinforcers were obtained from chain-pulling than were scheduled. When the two VI schedules were equal, the chain-pulling reinforcement rate was always greater than that for bar-pressing. This was a consequence of the strong preference shown for bar-pressing in terms of both allocated time and response rate. Although the schedule values were chosen so that overall reinforcement rate would be approximately constant, this strong preference caused considerable variation.

Using the data in Table 3.1, response, time and reinforcement ratios were calculated and used to plot the graphs of Figure 3.1. For each animal these are of log response ratio against log reinforcement ratio and log time ratio against log reinforcement ratio. Lines were fitted by the method of least squares to obtain values for the two parameters of Equation 2.2. The line of best fit and the proportion of variance accounted for by this line are shown with each graph.

All fitted lines show good agreement with the data in accounting for over 90% of the variance in the response or time ratios. Strong undermatching is evident in each case, with greater deviation from matching in the fits of time ratios to reinforcement ratios. Values of log b are all less than 0.0, denoting preference for bar-pressing. For both animals preference was more extreme in the allocation of responses than in time allocation.

Discussion

While the bias parameter of Equation 2.2 may accurately reflect preference for one response over another, undermatching appears to be a characteristic of concurrent performances with different required topographies. In this experiment, and those of Wheatley and Engberg (1978) and Davison and Ferguson (1978)

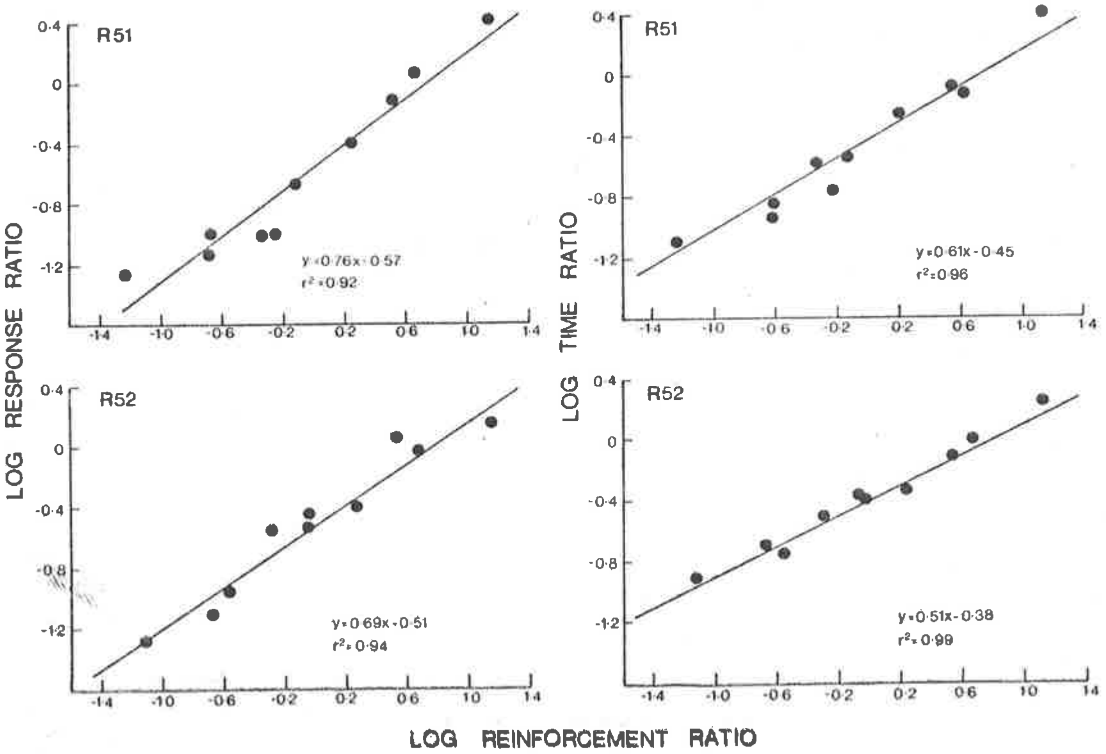

FIGURE 3.1: The logarithm of the ratio of response rates and allocated time as a function of the logarithm of the ratio of reinforcement rates. Fitted lines are shown with their equations and the proportion of variance accounted for by these equations.

strong deviations from matching in the direction of undermatching were found. Of all subjects in these three experiments only two of the five used by Davison and Ferguson showed slight overmatching. Although values of a were very similar for the two subjects in this experiment, there was considerable inter-subject variability in each of the other two experiments. Thus, it does not appear as if there is a standard degree of undermatching for each particular pair of responses.

Theoretical explanations of the results

A conclusion that undermatching is characteristic of concurrent performances with different response topographies is difficult to rationalise with Equations 3.1 and 3.2. Only if r_e is different for the two responses, and these values change with relative reinforcement rate, can undermatching be understood in terms of Equation 3.1. However, as mentioned above, $(r_1 + r_2 + r_e)$ represents the total reinforcement context and by definition does not vary according to the response under consideration.

In Section 2.9.2 Staddon's (1977b) and Catania's (1973) analyses of the relation between absolute response rates and reinforcement rates were described. Both interpreted the parameters k and r_e of Equation 3.1 differently to Herrnstein, and suggested further that these values of these two parameters should be positively correlated. If these values also covary with relative reinforcement rate, then some understanding may be gained of the undermatching observed here. However, this additional assumption does not form part of either account and would require considerable revision of the two analyses.

Donahoe's (1977) derivation of matching from the principle of reinforcement relativity was discussed in Section 2.6. His equations suggest that undermatching will occur if at least one of the responses has a non-zero operant level, and bias if the operant levels of the two responses differ. It is reasonable to assume that with two topographically different responses both of these pre-conditions may hold. The difficulty is in determining whether the operant level of either response is large enough to have a pronounced effect on the sensitivity of the organism to differences in reinforcement rate. Of the two responses in this experiment we would expect bar-pressing to have the higher operant level, and indeed this is required if Donahoe's account is to predict the appropriate direction for bias. However Norman and McSweeney (1978) found that relative rate of bar-pressing closely approximated relative reinforcement rate when that response was required in both alternatives of the concurrent schedules. It is therefore unlikely that bar-pressing's operant level is a sufficient explanation for the undermatching observed in this experiment. In addition, the results of the next experiment will show that undermatching still occurs when choice is between two responses with virtually zero operant levels.

None of the accounts of the basis of matching described in Chapter 2 is able to predict the strong undermatching which seems characteristic of concurrent performances with different response requirements. In extrapolating from the standard experimental design with response symmetry we seem to be going beyond the limits of the utility of these equations. However, other explanations for this strong undermatching should first be examined. de Villiers has suggested that use of a COD which is too small and hysteresis or order effects are the most common reasons for deviations from matching in the direction of undermatching.

Order effects and the COD

The COD used in this experiment was 5 sec in duration. Using rats, Shull and Pliskoff (1967) varied COD size in concurrent VI schedules. Their data suggested that matching should be closely approximated with a COD of 5 sec, although a larger COD value may have reduced the degree of undermatching. Wheatley and Engberg used a COD of 1 sec, and reported that this may have been too small, although a pigeon responding on schedules requiring treadle pressing in both components closely approximated matching with a COD of this size. Davison and Ferguson used a COD of 2 sec. CODs of this duration have been employed in experiments using pigeons which have found matching with the same response requirement for the two alternatives (e.g. Herrnstein, 1961).

It therefore appears as if COD duration cannot be invoked as an explanation of the undermatching in this experiment or those of Wheatley and Engberg and Davison and Ferguson. However further research should be conducted to determine whether larger CODs are required when there is an asymmetry in response requirements. While there are no a priori reasons for supposing this to be the case, the possibility deserves some investigation.

de Villiers (1977) has described how order effects may increase the probability of obtaining undermatching. Results from the one schedule repeated in this experiment, concurrent VI 120 secs VI 120 secs, may be used to assess any such effects. As Table 3.1 shows, the intervening schedules programmed higher rates of reinforcement for bar-pressing than for chain-pulling so that any order effects should be revealed as a decrease in response and time ratios from the first to the second presentation.

For R51, while the reinforcement ratio increased from 0.46 to 0.76, the response ratio increased from 0.10 to 0.21 and the time ratio from 0.26 to 0.28. Thus order effects may have influenced the time ratio but not the response ratio. For R51 the values were 0.84 and 0.93 for reinforcement ratios, 0.36 and 0.27 for response ratios and 0.42 and 0.40 for time ratios. There is some evidence of order effects for this subject, although not very powerful. The undermatching observed here may have been due in part to order effects.

An examination of Wheatley and Engberg's (1978) results suggests order effects, but with considerable variation between subjects. The effects were weak for two of the three subjects, but pronounced for the third. Since no condition was repeated in Davison and Ferguson's (1978) experiment order effects were impossible to assess.

It therefore appears as if the factors which promote undermatching when response requirements are symmetrical are not sufficient to account for the undermatching in these three experiments. While some variation from matching may have been due to the action of the factors, it is the very considerable degree of undermatching observed in the two subjects of this experiment, and several subjects from each of the others which remains unexplained.

Local response rates

In this experiment bias values obtained from response ratios were only slightly more extreme than those obtained from time ratios. The magnitude of the difference between the two was greater in both Wheatley and Engberg's and Davison and Ferguson's experiments, particularly the former. The direction, the same for all subjects in the three experiments, signifies that local rate of responding tends to be greater for the more preferred response. Thus, with reinforcement rates equal across the two alternatives, more time will be spent responding on the preferred manipulandum, and at a higher rate.

Results from Davison and Ferguson's experiment reveal no consistent difference between <u>a</u> values obtained from time ratios and those from response ratios. For all subjects in this experiment and in Wheatley and Engberg's <u>a</u> values obtained from response ratios were greater. This result is rarely found when the response requirement is the same for the two alternatives, and indicates a tendency to respond faster in the alternative yielding the higher reinforcement rate. The discussion in Section 2.4.3 and the results in Chapter 4 suggest that a higher local response rate in the less lucrative alternative is a property of concurrent performances when a COD is used. Why this generalization should be violated when there is an asymmetry in response requirements is unclear. However, we can state that the local response rate for each alternative depends upon both relative reinforcement rate and whether the response for that alternative is the preferred or non-preferred one.

Conclusion

The results of this experiment largely substantiate those reported earlier. With different response topographies required for the two alternatives of a concurrent schedule undermatching is more pronounced and more frequent than with symmetrical response requirements. This suggests that animals may show greater indifference to the distribution of reinforcements across alternatives when the response requirements differ. Such a conclusion is difficult to understand in terms of extant accounts of matching. Variations in the values of the parameters of Herrnstein's equations for absolute response rates are not sufficient to account for this lack of sensitivity.

It is likely that different degrees of undermatching will be obtained with different response pairs. The more similar the topography of the responses the less will be the deviation from matching. In this sense the results from concurrent schedules with different response requirements may resemble those from concurrent schedules with different reinforcers, discussed in Section 2.4. Because of this variability in the effects of relative reinforcement rate, research may be best directed toward ordinal scaling of responses and reinforcers rather than obtaining exact measures of preference (c.f. Navarick and Fantino, 1974).

While bias values reflected the preference for one response over the other, the degree of bias varied according to whether time allocation or the response distribution was used as the measure of behaviour. This difference indicated a tendency for the local response rate of the preferred response to be faster. We can therefore include response preference as a factor influencing local response rates.

3.3. EXPERIMENT 2

In the previous section it was shown that the bias parameter of Equation 2.2 reflects preference for one response form over another. Here, we will be concerned with whether the degree of bias is influenced by the type of reinforcer used. Herrnstein (1974) has stated that the critical assumption underlying the matching law is the constancy of $\underline{k}$ with variations in the type of reinforcer, motivational state, etc. The value of $\underline{k}$ should be dependent solely upon the form of the response in question and is the asymptotic rate of that response. Clearly then, bias for one response over another should also be independent of the type of reinforcer being employed.

The small amount of evidence which can be used to evaluate Herrnstein's assumption, mentioned in Section 2.9.1, has proved inconclusive. In some instances $\underline{k}$ has been shown to vary little, while in others the value of $\underline{k}$ has appeared to be critically dependent upon factors other than response form. A more exact test than previously used may be to offer each subject choice between two different responses under successive conditions differing in the type of reinforcer used. This was attempted in this experiment.

The basic schedule employed was multiple (concurrent VIx VIy) (concurrent VIx VIy). The two components of the multiple schedule were associated with two different reinforcers: milk and food. The VIx schedules arranged reinforcements for biting and the VIy schedules for licking. Scheduled rates of reinforcement were such that the overall rates of food and milk reinforcement remained approximately constant as relative reinforcement rates varied. For each response the same rate of reinforcement was scheduled in the two components, reducing the possibility of response rate changes due to generalization between components (i.e. induction, see Section 5.1).

Multiple schedules with concurrent VI VI components have been employed in previous experiments, but with complete symmetry of response and reinforcer type. The results of varying relative reinforcement rate in such schedules, reported in Section 2.4.4, show matching to be closely approximated within each pair of concurrent VI schedules. Any deviations from matching observed in this experiment should therefore be due to the asymmetries in the design.

From the results of the previous experiment we may expect both bias and undermatching within each component because of the difference in the response topographies required for reinforcement by the two concurrent VI schedules. Data from this experiment should validate this finding and, in addition, demonstrate whether the values of the two parameters $\underline{b}$ and $\underline{a}$ are dependent upon the type of reinforcer used. As mentioned above, Herrnstein's account predicts that $\underline{b}$ should be invariant with respect to reinforcer type because it is the ratio of the two $\underline{k}$ values. Since $\underline{a}$ has also been shown to deviate substantially from 1.0 when different response topographies are required, its value may also change with the reinforcer used. Unfortunately, because of limitations on the length of the computer program controlling the experiment and recording data, measures of time allocation could not be taken. The data of this experiment are therefore restricted to measures of overall response and reinforcement rates.

The topography of each of the responses chosen for this experiment resembles part of the topography of the consummatory response associated with one of the reinforcers. Biting is involved in eating food and licking in the drinking of liquids such as milk (at least for the rat). Several theorists have suggested that responses involved in the consummatory act should be more easily associated with the particular reinforcer being employed (e.g. Bolles, 1973 Seligman and Hager, 1972). Thus biting should be more readily associated with food than licking (although the difference may be small since licking can be involved in eating), while licking should be more readily associated with milk than biting. If such differential associability carries from acquisition to maintained performance, we should expect to see bias vary according to the reinforcer used. In particular, greater preference should be shown for biting in the food component than in the milk component.

Method

Subjects. Two male Wistar hooded rats, approximately 6 months old were used in this experiment. They had several months experience in this apparatus in which they were exposed to similar schedules to those used in this experiment. Access to food and water was allowed only during the hour following each session. Housing was in individual cages in a temperature- and humidity controlled room with a 12-hour day/12-hour night cycle.

Apparatus. The experimental chamber measured 23 cm x 22 cm x 21 cm high. The two sides were constructed of aluminium, with plexiglass front, back and top. The biting and licking manipulanda, food and water receptacles, and the stimulus lights associated with the last two were situated on one side. This is diagrammed in Figure 3.2. A bar and houselights were on the other side.

The biting manipulandum was constructed from the design specified by Azrin, Rubin and Hutchinson (1968). Two metal plates, 2.5 cm wide and 2.7 mm apart at the ends protruded 3.0 cm into the chamber. The plates were hinged so that both moved together if a downward or upward force were placed on them. A response registered only if a force totalling 2.25 N was exerted from above and below simultaneously. Plates travelled through a distance of 0.5 mm with this force.

The licking manipulandum used was a modified version of that described by Hulse (1960). This one differed in that no liquid could be delivered through the device. On the wall of the experimental chamber was a piece of 4.3 cm square, 3 mm thick plexiglass, with a 7 mm x 16 mm vertical slot down the centre. One cm behind this was a plexiglass tube 1.3 cm in diameter with a 2 mm brass rod embedded in the centre. The end of this rod, flush with the plexiglass tube, served as the contact relay and was wired to a Lafayette drinkometer circuit.

The contact relay was situated 6.0 cm below the biting manipulandum which was 8.6 cm above the floor of the chamber. On the left-hand side of this was a food magazine into which a Gerbrands pellet dispenser deposited 45 mg Noyes pellets. On the other side was a receptacle for milk drops which were

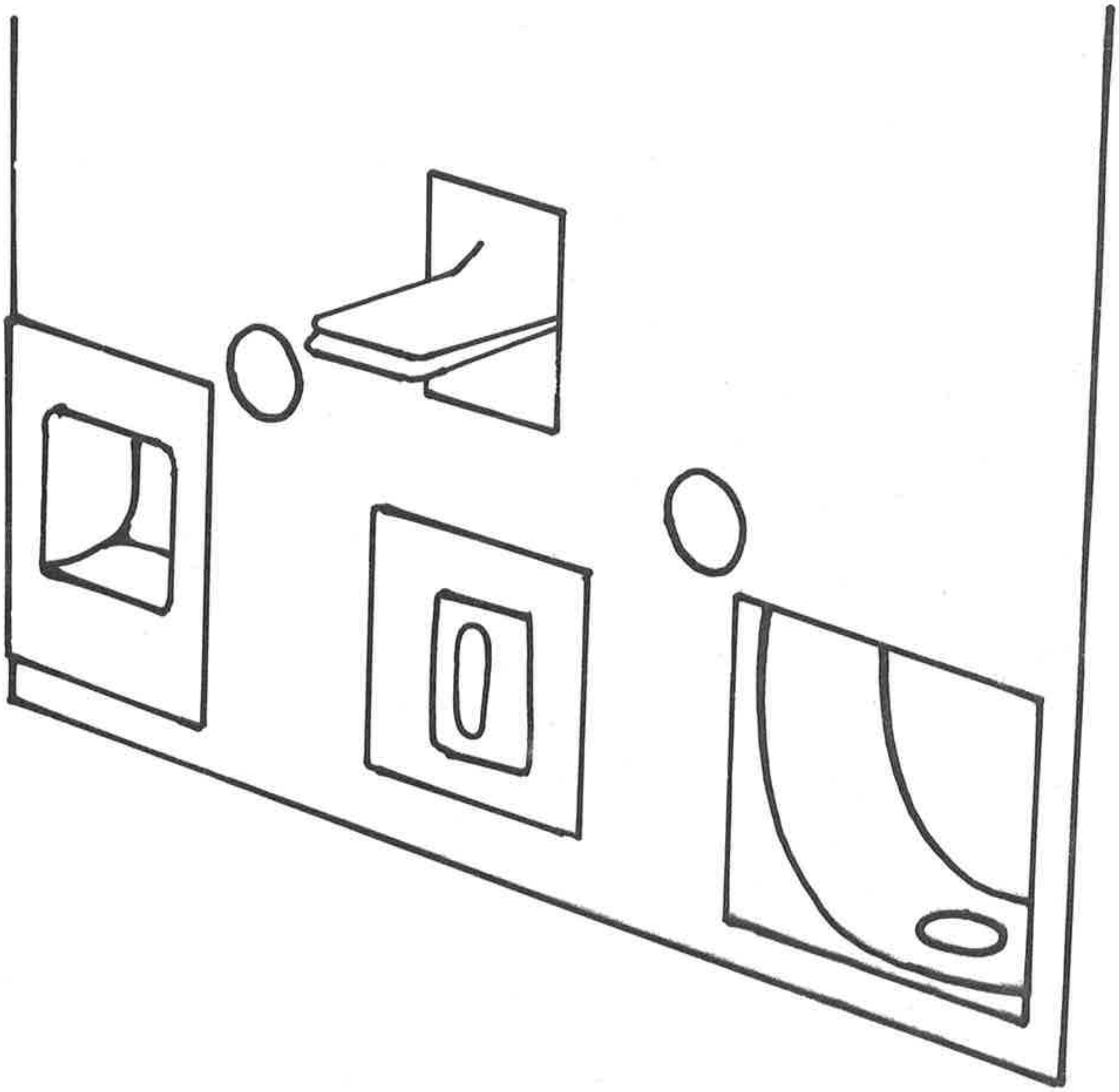

FIGURE 3.2: Diagram showing the main features of the apparatus used in Experiment 2. See text for description.

dispensed by a Lafayette liquid feeder. Drop size was set at .07 ml.

Adjacent to each of the feeders was a 1.7 cm diameter plexiglass disk which could be illuminated by a 3 W globe. Although two 3 W houselights were provided initially their use was terminated after 10 sessions as both animals spent much time biting them. Since one of the stimulus lights was always illuminated the chamber was never dark during sessions.

The chamber was placed in an individual, darkened cubicle with white noise to mask any external sounds. Control of the experiment and recording of data were performed by a PDP-11 computer.

Procedure

Since both animals were experienced in this apparatus no preliminary training was necessary. Through all conditions of the experiment the reinforcer available, and therefore the component in operation, was indicated by the stimulus light pattern. When responses were reinforced with food the light nearer the food magazine was on and that nearer the milk magazine was off, and *vice versa*. Delivery of a reinforcer, either a single food pellet or milk drop, was denoted by a 0.5 sec sounding of the buzzer.

The schedule used in all conditions was multiple (concurrent VIx VIy) (concurrent VIx VIy), with the VIx schedules arranging reinforcements for biting and the VIy schedules for licking. The four VI timers were independent, and each ran continuously unless it had set up a reinforcement or the other component of the multiple schedule was in operation. The intervals comprising the VI schedules were determined using Catania and Reynolds' (1968) formula with N=10 and were arranged in varying orders. A 5 sec COD was used throughout. This meant that a reinforcer for a bite could not be delivered within 5 secs of a lick, and *vice versa*. The operation of CODs was not affected by component changes.

The values of x and y were varied across the different conditions of the experiment. Each condition was maintained until for each of the four possible response types (biting for food, licking for milk, etc.), the ratio of responses made to reinforcements obtained from that responding showed no consistent directional change over three consecutive sessions. For each subject the values of x and y employed, the order of conditions and the number of sessions for which each condition was in operation are shown in Table 3.2. Sessions were of 60 min duration and were conducted 7 days per week.

Results

Sums over the last three days of each condition of responses made and reinforcers obtained are shown in Table 3.2. In common with the previous experiment the substantial bias toward one response (in this case, biting) meant that obtained reinforcement ratios differed substantially from the ratios of scheduled reinforcement rates. Consequently, overall reinforcement rates in each component varied across conditions, rather than remaining constant.

The data in Table 3.2 were used to plot the graphs of Figure 3.3. For each animal these are of log response ratio against log reinforcement ratio for each component. Lines of best fit, their equations, and the proportion of variance

TABLE 3.2: Sequence of schedules, number of sessions of exposure, and numbers of responses made and reinforcers obtained.

		VI size (secs)		Responses				Reinforcers			
				Food		Milk		Food		Milk	
Subject	Sessions	Bite	Lick	Bite	Lick	Bite	Lick	Bite	Lick	Bite	Lick
R21	24	120	120	5922	2107	3097	742	47	33	47	23
	14	65	780	6394	830	2181	39	86	12	76	2
	14	69	480	8242	689	3394	228	78	15	71	8
	11	80	240	6981	678	3437	172	64	18	66	9
	16	780	65	3779	3921	1265	1630	9	66	11	53
	11	480	69	3071	3143	1092	1403	12	63	12	51
	10	240	80	3866	2607	1516	1028	24	53	22	41
R22	21	120	120	6960	1228	4910	987	45	35	47	36
	8	240	80	7869	2548	3932	1929	22	58	19	58
	28	480	69	4389	2663	2280	1566	11	70	4	64
	7	780	65	1822	2543	865	1551	5	73	6	75
	8	80	240	9708	1516	2661	318	62	24	61	22
	22	69	480	11217	893	5028	451	75	15	74	11
	12	65	780	10240	665	4938	269	84	12	81	9

for which they account are shown with each graph. The equations of these lines were obtained by the method of least squares. In each case the line provided a good fit, accounting for over 90% of the variance in the response ratios.

Strong undermatching is evident in each of the graphs of Figure 3.3, substantiating the suggestion made in the previous section that undermatching characterizes concurrent performances when the alternatives differ in the response required for reinforcement. The degree of undermatching was not systematically related to the type of reinforcer used. For R21 the value of a was slightly greater for the food component, while for R22 it was greater for the milk component.

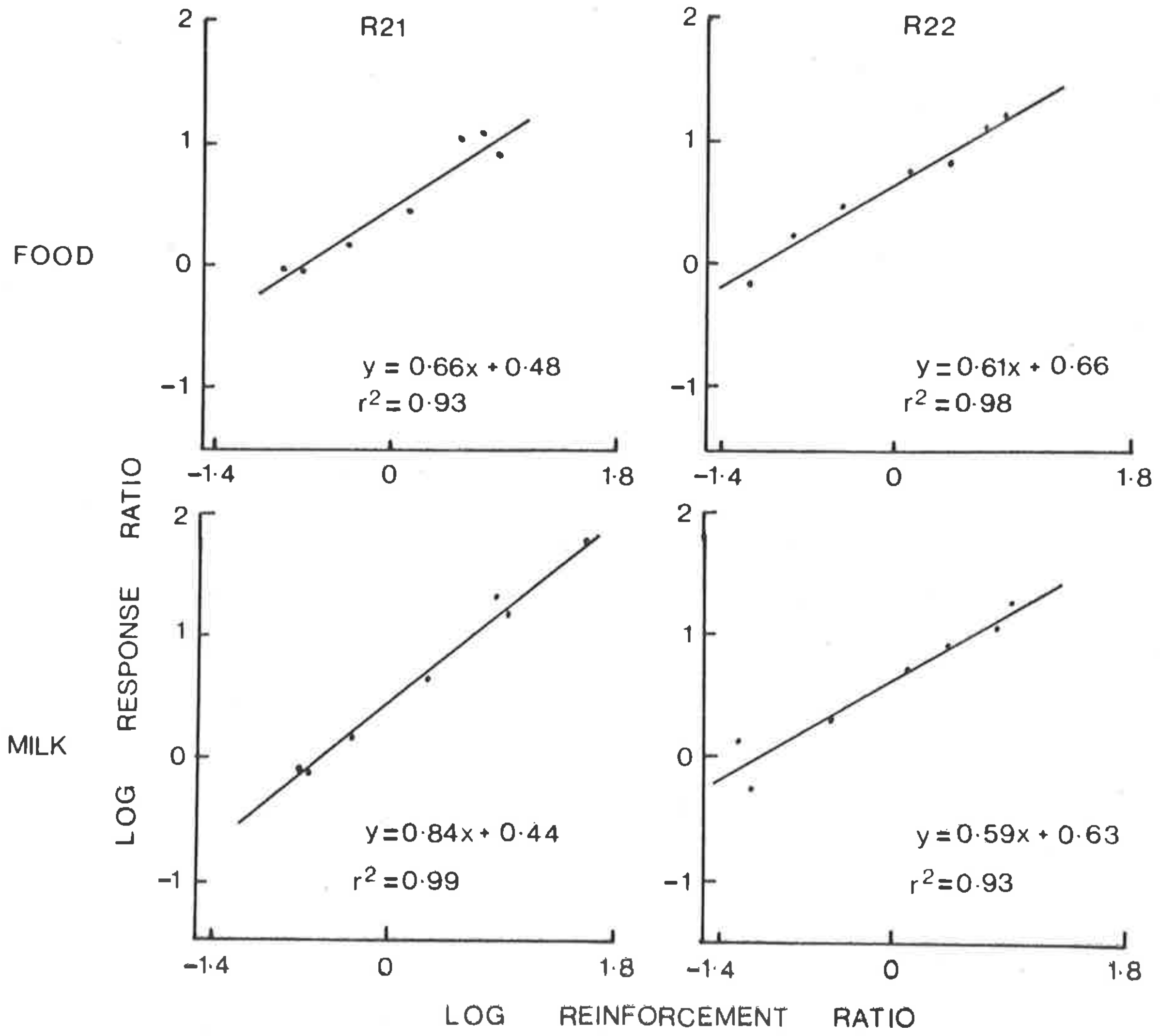

FIGURE 3.3: The logarithm of the ratio of response rates as a function of the logarithm of the reinforcement rates for each component. Fitted lines are shown with their equations and the proportion of variance accounted for by these equations.

Both animals exhibited a pronounced bias toward biting in the two components. Comparison of the pair of bias values obtained from each animal reveals that bias toward biting was stronger in the food component than in the milk component. The difference was proportionally greater for R21. Thus, in this experiment bias was influenced by the type of reinforcer used, and the direction of change was as predicted from theories concerning differential associability.

Discussion

While bias values indicated that preference for biting was more extreme when the reinforcer was food, the distribution of responses in a concurrent schedule is also influenced by relative reinforcement rate. The value of $\underline{b}$ characterizes the response bias and of $\underline{a}$, the way in which response ratios are determined by reinforcement ratios. In this experiment the $\underline{a}$ value varied, in an unsystematic way, according to the reinforcer maintaining the behaviour. A complete statement about relative preference for one response over another should include the effects of both bias and relative reinforcement rate. With equal reinforcement ratios in the two components, the ratio of bites to licks will be greater in the food component only for certain values of these ratios. These values may be determined using the equations of Figure 3.3.

Letting the subscripts B denote biting, L licking, F food and M milk, we have

$$\frac{R_{BF}}{R_{LF}} > \frac{R_{BM}}{R_{LM}} \qquad (3.1)$$

if and only if

$$b_F \left(\frac{r_{BF}}{r_{LF}}\right)^{a_F} > b_M \left(\frac{r_{BM}}{r_{LM}}\right)^{a_M} \qquad (3.2)$$

We wish to consider the situation where reinforcement ratios are equal in the two components. Substituting x for the reinforcement ratios in Equation 3.2 gives

$$b_f \; x^{a_F} > b_M \; x^{a_M} \qquad (3.3)$$

This may be solved for x by inserting appropriate values for the b and a parameters. For R21 the solution is $x < 1.55$ and for R22, $x > .036$.

Thus, with equal reinforcement ratios in the two components R21 will show greater preference for biting over licking as long as the reinforcement ratio does not exceed 1.55. For R22 the statement holds when the reinforcement ratio is greater than .036. Each of these values is, of course, the intersection of the lines of best fit for the food component and the milk component shown in Figure 3.3. By this means a statement about relative preferences can still be made when the degree of undermatching or overmatching varies with reinforcer type. In this case both bias and relative reinforcement rate must be considered.

While the point has been made that degree of preference for one response over another may change according to the reinforcer used, with many pairs of responses preference is likely to be fairly constant across a wide range of reinforcers. Consider the two responses employed in the previous experiment, for example. There are no clear reasons for predicting that the degree of preference for bar-pressing over chain-pulling will be influenced by whether the reinforcer is milk or food.

In this experiment, the responses were chosen specifically to maximize any chance of preference change, and yet the difference in the bias values in the two components was relatively small for both animals. Further research will reveal whether more significant preference changes occur with different combinations of responses and reinforcers.

Nevertheless, the fact that a preference change did occur,and in the predicted direction, suggests that the concept of differential associability may be extended to include maintained behaviour. While much research has been directed toward finding differences in the rate at which different behaviours are acquired with different reinforcers (e.g. Hinde and Stevenson-Hinde, 1973) little attention has been directed toward maintained behaviour. The ability of the theories of Bolles (1973), Seligman and Hager (1972) and others to predict preference shifts will be more exactly determined by future research. The results of this experiment have supported their predictions.

Conclusion

It was shown that while bias reflects preference for one response form over another, undermatching appears characteristic of concurrent performances with different response topographies. While this does not exclude the possibility of scaling response preferences, degree of preference was shown to change with reinforcer type, suggesting that only ordinal scaling will be feasible. However, two complicating factors must be considered. Firstly, the degree of undermatching may change with reinforcer type so that both bias and relative reinforcement rate effects must be considered. A means of expressing preference so as to include both these factors was considered here. Secondly, future research may reveal instances in which the direction as well as the degree of preference changes according to reinforcer type. If this is the case then even ordinal scales may be limited in their generality to certain reinforcer classes.

CHAPTER 4

CHANGEOVER RATIOS

4.1. INTRODUCTION

As was noted in Chapter 2, relatively little attention has been paid to possible changeover contingencies other than the COD. Some means of maintaining the independence of concurrent operants is required to prevent concurrent superstitions developing. If such a means is not employed the behaviour may be insensitive to the particular reinforcement contingencies employed. For example, the organism may constantly switch from one alternative to the other, emitting only a single response between changeovers. A COD or some other changeover contingency is required if the patterns of responding generated by each schedule are to more closely resemble those obtained from the schedules programmed separately (Catania, 1966).

One means of assessing the degree of sensitivity of the organism to the particular contingencies is by varying relative reinforcement frequency and examining consequent changes in the distribution of time and responses across alternatives. With a COD of sufficient length the familiar matching relation is closely approximated. However, the COD is the only contingency which has been shown to reliably produce matching (or a close approximation) across a wide range of values. Other procedures, such as punishment of changeovers by shock or TO seem only to result in matching across a small value range: undermatching is obtained if the value is too small and overmatching if it is too large.

The generality of the matching relationship is somewhat limited by the necessity of employing a COD. With any other changeover contingency it seems as if any of a whole family of functions may describe the relation between the distribution of reinforcements and the response and time distributions. It is useful then to explore possible alternatives to the COD. This may help extend the generality of matching, but may also lead to a better understanding of the basis of matching in the fine grain of behaviour: local patterns of responding, changeover rates, etc. For example, the COD generates an idiosyncratic pattern of post-changeover responding which Silberberg and Fantino's (1970) data suggest may be critical for the occurrence of matching.

The alternative to the COD examined in this series of experiments was the COR. An attempt was made to explore the properties of the COR in order that its effect on relative reinforcement rate be best understood. The COR is of particular interest for several reasons. Firstly, the evidence described below suggests that in contrast to the COD, deviations from matching obtained with a COR tend to be in the direction of overmatching. Secondly, the COR is simply a requirement for switching, whereas the COD is imposed after the requirement for switching has been met. In addition the COR more closely mimics contingencies for changing from one source of reinforcement to another observed outside the laboratory. Such requirements usually involve a certain amount of "work" rather than time constraints on the availability of reinforcement.

The effect of the COR on matching has been examined in four different experiments, all employing pigeons. Stubbs and Pliskoff (1969) scheduled relative reinforcement rate at 0.75, with the COR set at 1 or 20 responses. Matching of time and response proportions to reinforcement proportions was closely approximated with COR = 1, but overmatching was obtained with COR = 20. The response proportions showed stronger overmatching than the reinforcement proportions. Guilkey, Shull and Brownstein (1975) used a COR of 2 responses and varied the reinforcement proportion across the values .75, .50 and .25. Results from the three subjects showed that matching was closely approximated but with some tendency to overmatching in the response proportion data.

Two recently reported experiments have provided more complete information on matching with a COR. Pliskoff, Cicerone and Nelson (1978) set the COR at either 5 or 10 responses and varied relative reinforcement rate. Their data have been reinterpreted in terms of Equation 2.2 and are presented in in Table 4.1. Caution should be exercised in generalizing from any single curve since only 4 points were involved in each of the fitted lines. However, the data do reveal a strong tendency to overmatching. The deviation from matching was more pronounced when the COR was 10 responses and when response rather than time data were considered.

In the second of these experiments, Marcucella and Margolius (1978), a slightly different procedure was employed. In the other three experiments VI timers were halted during the time between the first and last changeover responses, while in Marcucella and Margolius' they were not interrupted by changeovers. While these authors neither used Equation 2.2 nor presented raw data, it is clear from the graphs in their report that matching was closely approximated with both COR values used (7 and 10 responses). There was some tendency to overmatching in

TABLE 4.1: Values of the parameters and the proportion of variance accounted for (r^2) by fits of Equation 2.2 to the data from Pliskoff, Cicerone & Nelson (1978).

		Response			Time		
COR	Subject	b	a	r^2	b	a	r^2
10	1	1.17	1.81	0.92	1.16	1.50	0.88
	2	0.83	1.14	0.85	0.69	1.10	0.83
	3	1.03	2.03	1.00	1.10	1.63	0.98
5	A	1.08	1.45	0.96	1.12	1.35	0.96
	B	0.97	1.13	0.99	0.96	1.02	0.98
	C	0.97	1.16	0.91	0.97	0.90	0.96

response data of 2 of the 3 subjects, but not as strong as that obtained by Pliskoff _et al_ (1978).

It remains to be determined whether, as the data suggest, overmatching is more likely when the VI timers are halted during changeovers. Also, the range of COR values over which matching can be obtained is not revealed by these experiments. With COR = 1 we would expect undermatching since this is equivalent to a COD of 0.0 secs using the changeover manipulandum procedure. However, Stubbs and Pliskoff's (1969) data do not agree with this prediction. There may therefore be an important difference between the two methods of programming concurrent operants. As the COR is increased from 1 response the likely outcome may change from matching to overmatching. This tendency appears to be stronger with response rates rather than time allocation as the dependent variable.

Several other experiments have explored the effects of COR size on concurrent performances. Stubbs, Pliskoff and Reid (1977) described a study with pigeons in which CORs of 1, 2, 5, 10 and 20 responses were used in the different conditions. Equal VI schedules were concurrently programmed and VI timers were halted during changeovers. Their dependent variable was interchangeover time: time allocated to one alternative divided by the number of changeovers from that alternative to the other. Interchangeover time increased as a power function of COR size over the range 5-20 responses. Their reanalysis of the results of several experiments showed that power functions also described the effects of COD size on interchangeover time. Thus changeover rate seems to decrease in the same fashion with increases in either COR size or COD length.

An early study by Findley (1958) used progressive ratio (PR) and progressive interval (PI) schedules. In such schedules the number of responses required for reinforcement (PR schedules) or the interval length (PI schedules) increases with each successive reinforcement, while a pause in responding of predetermined length resets the values to their minimum level. Findley found a decrease in the rate of switching between PR schedules when the COR was increased. He also examined preference for concurrent PR and concurrent PI schedules with asymmetrical CORs required for switching in the two directions (that is, the COR for switching from schedule A to schedule B was different from that required to switch from B to A). Pigeons exhibited a strong preference for the schedules with a lower switching-into (and therefore higher switching-out) requirement.

While the effects of COD size on concurrent performance have been extensively researched (results from varying symmetrical COD size have been reported by Allison and Lloyd, 1971; Catania, 1966; Pliskoff, 1971; Shull and Pliskoff, 1967; Silberberg and Fantino, 1970, and Stubbs and Pliskoff, 1969, while effects of asymmetrical CODs have been reported by Pliskoff, 1971) such is not the case with CORs. In addition, the only experiment to use CORs which did not interrupt VI timers was Marcucella and Margolius (1978). The present experiments examined the effects of COR size in a procedure using timers uninterrupted by execution of CORs. Under such conditions the pattern of local reinforcement rate following a COR should be similar to that following a COD.

4.2. EXPERIMENT 1

The first experiment was designed to examine the effects on changeover rate and local response rate of increases in COR size. A range of symmetrical CORs was employed with equal VI schedules concurrently programmed. Stubbs and Pliskoff (1969) showed that local response rate tended to increase when the COR was changed from 1 to 20 responses while Stubbs *et al* (1977) found that changeover rate decreased with increases in COR size.

In both of these experiments VI timers were halted during changeovers. While the function relating changeover rate to COR size may not alter with the alternative procedure employed here, there may be an effect on local response rates. If larger CORs take longer times to execute, local reinforcement rate will increase with COR size. This should then be reflected in associated changes in local response rate.

Method

Subjects. Four male Wistar hooded rats, experimentally naive and approximately 3 months old at the start of this experiment were maintained on a 23 hour food deprivation cycle. Housing was in individual cages in a temperature and humidity controlled room with a 12 hour day/12 hour night cycle. Access to water was free.

Apparatus. The experimental chambers measured 22 cm x 22 cm x 21 cm. In each a 5 cm long bar, which could be operated by a force of 0.10N, was located in the centre of one panel and protruded 1 cm into the chamber. A food magazine into which 45 mg Noyes pellets could be deposited by a Gerbrands pellet dispenser was situated directly below this. Above the bar was a circular plastic disc, 2.5 cm in diameter, which could be illuminated by a 3W stimulus light. Two houselights, also 3W, were on the opposite side of the chamber. Situated 10 cm from the bar was a chain which fell 14 cm from the ceiling and supported a 2.3 cm diameter ring. A pull of 0.41N in a downward direction on the chain operated a microswitch. A buzzer was mounted on the plate supporting the chamber, and the chamber was enclosed in a sound resistant shell with an exhaust fan in one wall. Control of the experiment and recording of data were performed by a PDP-11 computer.

Procedure. Subjects were hand-shaped to press the bar and exposed to a schedule of continuous reinforcement for three 50 min sessions. The chain was not in the chamber during this stage. Throughout, delivery of a reinforcer was signalled by a 0.5 sec sounding of the buzzer.

Following this preliminary training the animals were immediately exposed to a concurrent VI 1-min VI 1-min schedule with COR=1. Reinforcers could be obtained according to the VI schedules by bar-pressing, while chain-pulls were required for switching between schedules. The two schedules were differentiated by the stimulus light above the bar being on or off. During this stage a single chain-pull was required for switching and the stimulus light altered when the chain was pulled. No shaping of the chain-pull response was required. In later stages, when the COR was greater than one, the first chain-pull turned off the house-lights, and the stimulus light if it was on. Houselights came on again, and the stimulus light if appropriate, when the required number of chain-pulls for switching was met. Timing for the VI schedules was continued during the houselights off period but reinforcers could only be obtained when the houselights were on.

Five values of the COR were used: 1, 2, 5, 10 and 20 responses. Exposure to each of these continued until all animals showed no consistent directional change in response or changeover rates over 3 consecutive sessions. Respectively, the number of sessions taken to reach this criterion was 16, 36, 13, 16 and 19. For each animal coefficients of variation (the ratio of the standard deviation to the mean) computed for each component from these 3 sessions did not exceed 0.20 for either local response rates or changeover rates. Sessions lasted 50 mins and were conducted seven days per week.

The VI schedules used throughout each consisted of an arithmetic series of 12 intervals ranging from 0.5 sec to 2 min. The two schedules involved the same intervals but in a different, irregular order.

Results and Discussion

In Table 4.2 sums over the last 5 days of each condition are shown for the numbers of responses, changeovers, reinforcers and the time spent in each schedule. Because of the decrease in changeover rate and the increase in the amount of time taken to complete each changeover, the number of reinforcers obtained decreased as the COR was made larger. No consequent differential satiation effect was revealed by inspection of cumulative records.

TABLE 4.2: The distributions of reinforcers, responses and time between the stimulus-light-on (ON) and the stimulus-light-off (OFF) schedules and the number of changeovers made. The data are sums over the final five sessions of each condition. Numbers of responses made and reinforcers obtained when the stimulus-light was on as a proportion of the total number (prop) are also included.

		Reinforcers			Responses			Time (secs)		
Subject	COR	ON	OFF	Prop	ON	OFF	Prop	ON	OFF	Changeovers
R1	1	211	211	0.50	2164	2257	0.49	7010	7010	1519
	2	199	208	0.49	4023	3947	0.51	6566	6654	778
	5	198	179	0.53	4954	3951	0.56	6409	5209	371
	10	183	181	0.50	4459	4347	0.51	4861	4737	305
	20	156	122	0.56	5571	3399	0.62	6019	3984	139
R2	1	225	225	0.50	3022	2971	0.50	6749	6337	2711
	2	222	226	0.50	2599	2429	0.52	5772	5533	2198
	5	214	209	0.51	2213	1880	0.54	5004	4429	1118
	10	182	184	0.50	3131	3593	0.47	4506	5455	394
	20	142	80	0.64	6954	3743	0.65	7454	4191	37
R3	1	229	229	0.50	2567	2556	0.50	6326	6669	3078
	2	227	230	0.50	2391	2395	0.50	4463	4461	3063
	5	218	216	0.50	1995	1915	0.51	3637	3575	1558
	10	186	186	0.50	1708	1632	0.51	3637	3575	1558
	20	151	158	0.49	1944	2412	0.45	3001	3690	337
R4	1	230	230	0.53	4933	4472	0.53	6763	6441	2666
	2	224	227	0.51	6852	6536	0.51	6552	6144	1222
	5	215	219	0.48	6237	6789	0.48	5470	5894	756
	10	183	191	0.44	6094	7647	0.44	5170	6207	327
	20	157	100	0.64	8958	5107	0.64	7655	4515	72

The number of responses made when the stimulus light was on as a proportion of the number in both schedules, and the proportion of reinforcers obtained from that schedule are also shown for each animal in each condition in Table 4.2. Matching was closely approximated throughout, parallelling the results of Shull and Pliskoff (1967), who found little variation in the proportions of time spent, responses made, or reinforcers obtained in one of a pair of equal VI schedules when the COD was increased from 0 to 20 secs.

Increasing the COR had the effect of decreasing the changeover rate. This is shown in Figure 4.1 where changeover rate is plotted against COR size on logarithmic coordinates, with lines fitted by the method of least squares. R2 and R4 showed a sharp drop in changeover rate, not evident in the data from R1 and R3, when the COR was increased from 10 to 20. The data reported by Stubbs et al (1977) showed a similar power relationship when replotted in the form of Figure 4.1, except that for two of the three pigeons the changeover rate increased when the COR was increased from one to two responses.

Hunter and Davison (1978) derived equations relating changeover rate to COD size and either response rate, time allocation or reinforcement rate in the two alternatives. For response rate the equation is -

$$CO_{ij} = b \left[(COD_{ij} + G)(COD_{ji} + G)\right]^{e} \frac{R_i R_j}{\Sigma R} \qquad (4.1)$$

where CO_{ij} is the changeover rate from component i to component j, COD_{ij} is the COD for that changeover and COD_{ji} the COD for

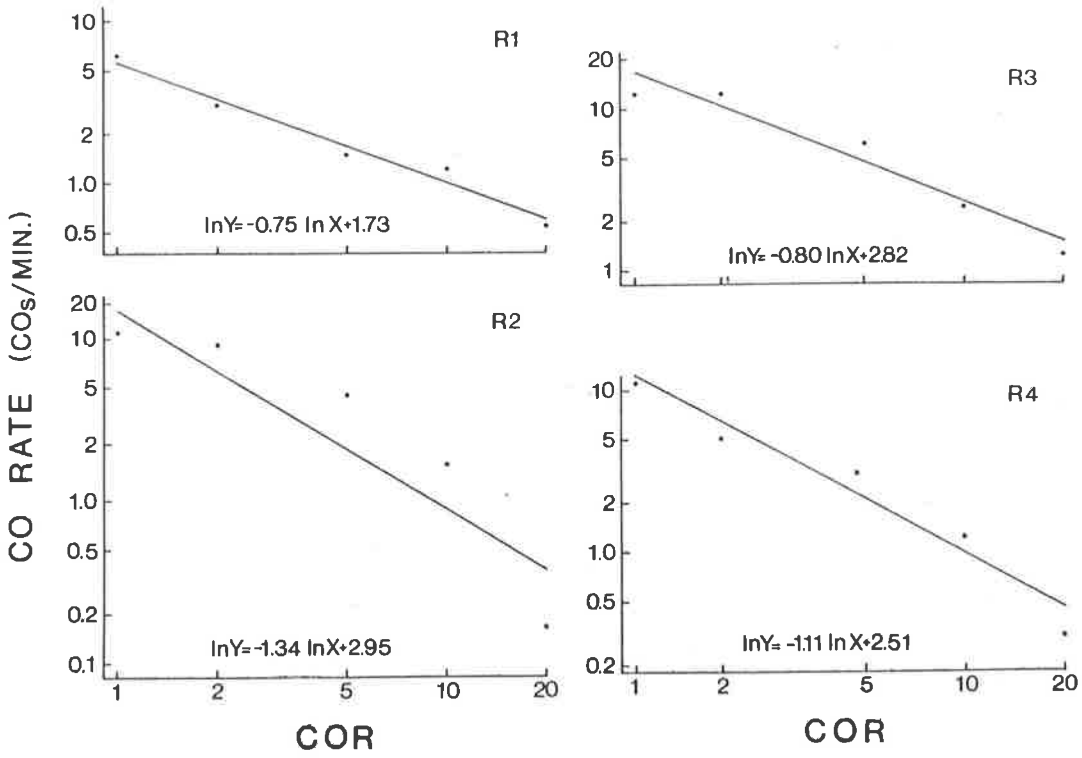

FIGURE 4.1: Changeover rate as a function of COR size. Natural logarithmic coordinates are used and lines of best fit are shown with their equations. (ln X denotes the natural logarithm, or logarithm to base e of X.)

the changeover in the opposite direction. R_i and R_j are the response rates in the two components. The parameters b, G and e are empirically derived by a curve-fitting procedure. They suggested that G may represent the time required to make a changeover. Stubbs et al's (1977) analysis of changeover rates also suggested that there is an effective COD of 1 - 2 secs operating in most experiments because of this time period.

Equation 4.1 may be applied to the COR data here. Let CO_{12} represent the changeover rate from the light-on to the light-off component. For a first approximation G may be set at zero, particularly since CORs are defined by number rather than time. With symmetrical CORs we then have the equation

$$CO_{12} = b\ (COR)^{2e}\ \frac{R_1 R_2}{R_1 + R_2} \tag{4.2}$$

This was fitted to the data in Table 4.2 and the results are presented in Table 4.3. Values of the parameters b and e fall within the range obtained by Hunter and Davison in their application of Equation 4.1 to the results of a number of experiments. Equation 4.2 also provides a fairly good fit, accounting for over 90% of the variance in two of the four cases. When G was added to Equation 4.2 the variance proportion was only slightly higher and values of G were very small (less than 0.10). The reasonably good account of changeover rate provided by Equation 4.2 shows that Hunter and Davison's analysis is applicable to performance on concurrent schedules in which either CORs or CODs are employed.

TABLE 4.3: Values of the parameters and the proportion of variance accounted for (r^2) by fits of Equation 4.2 to the data of Experiment 1.

Subject	b	e	r^2
R1	0.66	-0.75	0.92
R2	1.01	-0.37	0.79
R3	1.35	-0.21	0.87
R4	0.54	-0.64	0.95

Local response rate, the number of bar-presses divided by the amount of time that the houselights were on, tended to rise as the COR was increased. Figure 4.2 shows the line fitted by the method of least squares to the points obtained by plotting local response rate against the COR in logarithmic co-ordinates. This increase may reflect an elevated post-changeover response rate, corresponding to that which occurs when a COD is employed. Catania (1962) suggested two explanations to account for this elevation. It could be a compensation for time spent responding in the other schedule, or a reflection of the increased local probability of reinforcement following a changeover. Thus increasing the COR, because it reduced changeover rate would also have the consequence of increasing local response rate. This effect could be magnified by a second effect. Because the VI timers continued to run during the houselights-off period, lengthening this period with longer CORs increased the possibility of immediate reinforcement after a changeover. The behaviour of R3 provides evidence for the second effect alone. It showed negligible change in changeover rate, but a sharp drop in houselights-on time when the COR was increased from 1 to 2 (see Table 4.2). For this animal local response rate increased significantly between these two conditions. Such an effect will not appear when VI timers are interrupted by changeovers.

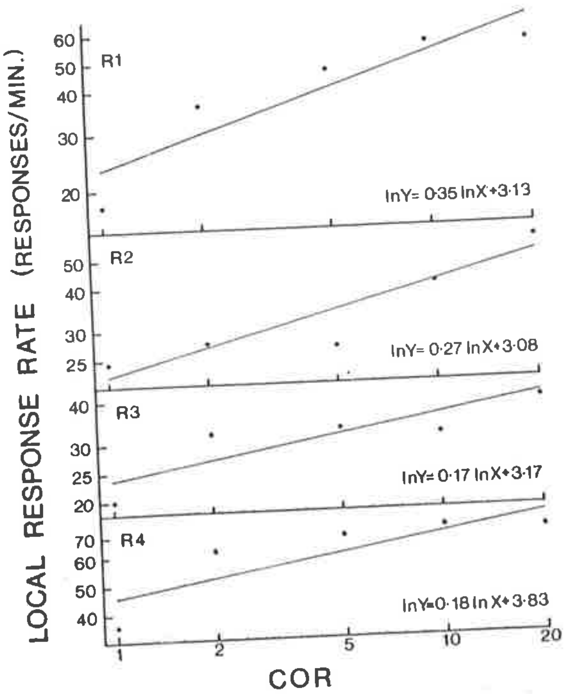

Figure 4.2: Local response rate (number of bar-presses divided by total houselights-on time) as a function of COR size. Natural logarithmic coordinates are used and lines of best fit are shown with their equations.

4.3. EXPERIMENT 2

In the first experiment higher local response rates followed longer CORs. This observation suggests that the matching relation may not hold if asymmetrical CORs were employed. If the higher local response rate is dependent on the length of the immediately preceding changeover period, during which probability of reinforcement is zero, then responding is likely to be faster during the schedule with the higher switching-into COR. However, the consequent increase in the number of reinforcers obtained would be small. Because the VI timers continue to operate regardless of the schedule in effect, reinforcement rate is highly dependent on the changeover rate, so that with a constant total number of changeover responses required, but differentially assigned to the two directions, the distribution of reinforcers should remain relatively constant with manipulation of the assigned CORs. In this experiment the sum of the two CORs was kept constant at 10 chain-pulls, but all possible asymmetrical combinations were explored.

Method

Subjects and Apparatus. All animals from Experiment 1 began this experiment but R2 was excluded after 2 weeks because of illness. The results obtained from R2 have not been used.

The apparatus was the same as that used in Experiment 1.

Procedure. The five possible pairs of CORs with a sum of 10 are 5/5, 6/4, 7/3, 8/2, and 9/1. Data pertaining to the first of these had already been obtained in the course of performing Experiment 1, so that this condition was not repeated. Each of the others was employed for each subject on five consecutive days, with the opposite pair for the following five. Thus the order of conditions was 6/4, 4/6, 7/3, 3/7, 8/2, 2/8, 9/1, 1/9, where the first number of each pair indicates the COR required to move from the VI schedule associated with the stimulus light on to that associated with the stimulus light being off. All other aspects of the procedure replicate those associated with Experiment 1.

For each animal coefficients of variation computed for each component from the last 3 days of each condition did not exceed 0.14 for local response rates and 0.22 for changeover rates.

Results and Discussion

Table 4.4 gives the total number of changeovers made and the number of reinforcers obtained, responses made and the amount of time spent in each of the schedules. For all COR pairs these are sums over the last 3 days of each condition, including the data for 5/5 which were derived from the results obtained in Experiment 1. The only consistent change in changeover rate evident for any of the animals is a tendency to a low rate when the COR pairs were 9/1 and 1/9.

Confirmation of the prediction that local response rate would be higher for the schedule associated with the higher switching-into COR is provided by Figure 4.3. The ratio of the two local response rates (stimulus-light on/stimulus-light off) has been plotted against the COR required for switching-into the VI schedule associated with the stimulus light being on (the second figure in the COR pairs of Table 4.4). All

TABLE 4.4: The distribution of reinforcers, responses and time between the stimulus-light-on (ON) and the stimulus-light-off (OFF) schedules and the number of change-overs made. The first number in each COR pair indicates the COR required for switching from the ON to OFF schedules, the second the COR for switching from OFF to ON. The date are sums over the final three sessions of each condition.

		Reinforcers		Responses		Time (secs)		
Subject	COR pair	ON	OFF	ON	OFF	ON	OFF	Changeovers
R1	5/5	121	103	3338	2186	4170	2842	221
	6/4	113	124	2692	3790	3020	3781	268
	4/6	125	109	3976	2361	3755	2552	281
	7/3	116	121	3249	3780	3257	3606	251
	3/7	127	109	3839	2109	3972	2533	323
	8/2	110	114	3076	3255	3039	3040	326
	2/8	126	104	5455	2271	4328	2282	287
	9/1	82	119	1748	6505	1716	4916	206
	1/9	110	62	6787	1644	4838	1419	146
R3	5/5	131	130	1267	1197	2316	2228	914
	6/4	129	131	1434	1721	2261	2577	791
	4/6	130	128	1356	1310	2160	2115	991
	7/3	129	130	1304	1597	1999	2472	807
	3/7	128	129	1546	1326	2287	2175	784
	8/2	129	128	1146	1427	1956	2380	743
	2/8	131	128	1317	1107	2287	1926	836
	9/1	128	134	1211	2537	1939	3482	749
	1/9	132	123	2649	1042	3349	1643	646
R4	5/5	129	132	3568	3997	4475	3543	454
	6/4	125	114	4495	3723	3485	2987	382
	4/6	126	120	4896	3908	3695	3080	375
	7/3	120	120	5029	5285	3696	3958	295
	3/7	128	120	5825	3934	3976	2860	394
	8/2	120	127	3471	5137	2711	3665	398
	2/8	132	112	6750	3603	4687	2654	320
	9/1	99	118	4146	6910	3103	4662	225
	1/9	128	90	8342	3173	5252	2282	230

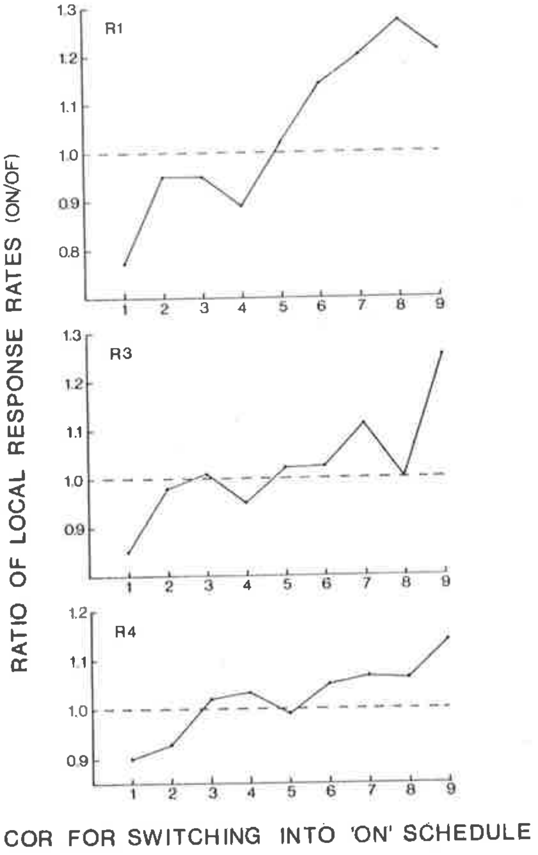

FIGURE 4.3: The ratio of local response rates (rate of responding when the stimulus light was on divided by the rate of responding when it was off and houselights were on) as a function of the COR required for switching into the stimulus-light on schedule. Dashed lines indicate equality of local response rates.

points except three (two in the graph of R4 and one in that of R3) indicate that the local response rate was higher following the longer COR. The deviation from equality showed some tendency to increase as the difference between the two CORs increased, although this was not entirely consistent for any of the animals.

From these results it would be expected that as the difference in the two CORs became larger, the proportion of responses made in each schedule would deviate from the proportion of reinforcers obtained from that schedule. Figure 4.4 shows for each animal the proportion of reinforcers obtained and responses made in the stimulus-light on schedule as a function of the required switching-into COR. The variation in the proportion of responses is much greater than that for reinforcers. Both increased as the switching-into COR became greater, but the deviation from indifference was more exaggerated for the proportion of responses made. The results for all animals show the difference between the 2 proportions to be high when the COR pairs were 9/1 or 1/9. Thus there was a strong drift from matching as the asymmetry in the two CORs was increased, with a greater proportion of responses being made in the schedule associated with the larger switching-into COR.

Whether the deviation from matching was due solely to the differential local response rates can be ascertained from an examination of the way each animal apportioned time to the two schedules, which is also shown in Figure 4.4. The proportion of time spent in the stimulus-light-on schedule shows a similar functional relationship to the COR required for switching into that schedule as does the proportion of

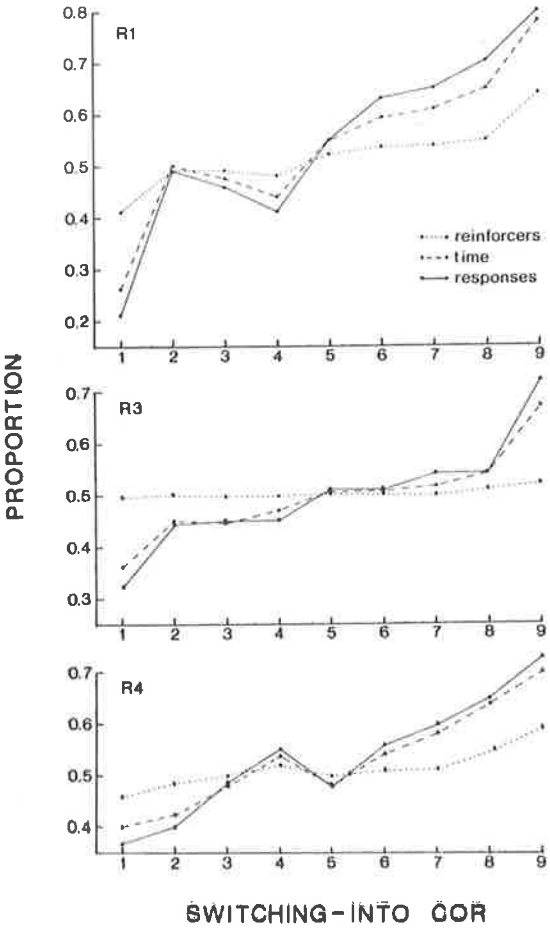

FIGURE 4.4: The proportion of responses, time, and reinforcers associated with the stimulus-light-on schedule as a function of the COR required for switching into that schedule.

responses. However, all animals tended to apportion the available time so that the matching of proportion of time spent to proportion of responses made was closer in almost all conditions than that derived when the proportion of obtained reinforcers was considered. This indicates a dual effect of asymmetrical CORs: tendencies to spend more time in the schedule associated with the larger switching-into COR and to respond faster in that schedule. The fact that proportion of time matched proportion of responses more closely than it matched the proportion of obtained reinforcers suggests that the former effect is the stronger one.

These findings contrast with those of Pliskoff (1971) who employed symmetrical and asymmetrical CODs. Longer switching-into and switching out CODs tended to increase the time allocated to a schedule, but the latter was the more powerful. The pigeon in that experiment exhibited a deviation from matching, but in the direction of assigning more responses and time to the schedule associated with the shorter of the two CODs. Further, there was no consistent difference in local response rates associated with differences in COD length.

4.4. EXPERIMENT 3

It has been shown that local response rates tend to be higher after longer CORs and if asymmetrical pairs of CORs are employed more time and responses are apportioned to the schedule associated with the longer siwthing-into COR. It is possible that a COR punishes the responding which precedes it, so that with asymmetrical CORs the punishing effect is smaller for the schedule which has a larger switching-into and therefore lower switching-out COR.

To determine if the size of the COR can function as a punisher, one COR was kept constant while the other increased in size as more time was spent in the schedule for which this variable COR was the switching-out requirement. The schedule associated with the variable switching-out COR also arranged reinforcements at twice the rate of the other. If longer CORs have a stronger punishing effect, less time should be spent and fewer responses made in this schedule than would be expected at the basis of its relative reinforcing value. If the size of the switching-out COR is of minor importance then it would be expected that its size would be large, as a larger proportion of time would be spent in the schedule yielding a higher reinforcement rate.

Method

Subjects and Apparatus. R1, R3 and R4 were used again in this experiment, and the apparatus was the same as that employed in the previous two experiments.

Procedure. Two VI schedules were arranged concurrently: the first a VI 2-min and the second a VI 1-min. The COR required for switching from the first to the second had a constant value of 10 chain-pulls, while the COR for a switch in the opposite direction had an adjusting value. Immediately after the animal switched into the VI 1-min component the COR to switch-out was 2 chain-pulls, but every 5 secs spent in that schedule caused the COR to increment by 1. This schedule was associated with the stimulus light being off.

All other procedural details were the same as those for Experiment 2. While each animal's rate showed no consistent trends in either response rate, changeover rate or mean adjusting COR between the fifth and tenth sessions, the schedule was run for a further 5 sessions to ensure stability. For each animal coefficients of variation computed for each component with data from these last 5 sessions did not exceed 0.17 for local response rates and 0.23 for changeover rates.

Results and Discussion

Table 4.5 shows the mean of the adjusting COR, the distributions of responses, times and reinforcers between the two schedules, and the total number of changeovers made. These data all refer to the last five days of exposure to the schedule. Values for the proportions of responses made, time spent and reinforcers obtained in the VI 2-min schedule and the local response rates were derived from these and are also shown in Table 4.5.

All animals exhibited strong deviation from matching by their assignment of proportions of time and responses to the VI 2-min schedule greater than the proportion of reinforcers obtained from that schedule. All obtained fewer than half of their reinforcers from this schedule, but R1 and R4 assigned more than half of their responses and time to it. For all animals the deviation is stronger when responses are considered than when the time distribution is compared to the reinforcer distribution. This is further borne out by consideration of the local response rates: all animals responded faster in the VI 2-min schedule.

Since adjustment of the variable COR was dependent only on apportioned time and not responses made, it might be expected that the local response rates would be approximately

TABLE 4.5: The distribution of reinforcers, responses and time between the stimulus-light-on (ON) and the stimulus-light-off (OFF) schedules, the number of changeovers made summed over the final five sessions. The COR means were calculated from frequency distributions taken during this period. Numbers of responses made, reinforcers obtained and time spent in the stimulus-light-on condition as a proportion of the respective totals are shown in brackets; local response rates were calculated from these data.

	Mean value of adjusting	Reinforcers		Responses		Time(secs)		Local response rates (Rs/min)		
Subject	COR	ON	OFF	ON	OFF	ON	OFF	ON	OFF	Changeover
R1	5.66	99	134	8124	2688	6289	3114	77.5	51.4	298
		(0.43)		(0.74)		(0.67)				
R3	3.14	113	209	2211	2373	3473	3775	38.2	37.7	862
		(0.35)		(0.48)		(0.48)				
R4	4.95	118	171	10630	5733	6870	4304	98.8	79.9	506
		(0.41)		(0.65)		(0.62)				

equal, or that some compensation for the lesser amount of time spent would be made. In the latter case the local rate in the VI 1-min schedule would be greater than in the VI 2-min, but the opposite was true. One interpretation is that the COR has a rate-depressing effect on behaviour which precedes it, even though that responding does not affect COR size.

4.5. EXPERIMENT 4.

This experiment was designed to provide data on local patterns of responding and reinforcement while confirming the results of the first two experiments. Experiment 2 established that more time and responses were allocated to the schedule with the larger switching-into COR. This preference could not solely be accounted for in terms of differences in reinforcement rate. In addition, a greater degree of preference was revealed by response proportions than time proportions, indicating that local response rate was faster in the schedule with the larger switching-into COR. One possible explanation for this fact is that CORs generate a pattern of immediate post-changeover response bursting as the COD does, and that this bursting is more extreme, or lasts for a longer period, following larger CORs.

Such a pattern may be understood if local reinforcement rates are higher immediately after longer CORs. Thus, two questions in particular were addressed in this experiment: does the COR generate the pattern of immediate post-changeover response bursting that the COD does, and how do patterns of response and reinforcement rates change as a function of COR size? These problems were examined by looking at changes in patterns of responding and reinforcement following varying switching-into CORs, with the switching-out COR held constant.

Method

Subjects and Apparatus. R3 and R4 were used in this experiment and the apparatus was the same as that employed in the previous experiments.

Procedure. Local response and reinforcement rates were derived from data taken from the schedule associated with the stimulus light being off. The terms switching-into and switching-out are thus used with reference to this schedule.

Two switching-out COR values of 5 and 10 chain-pulls were each paired with switching-into CORs of 2, 5, 10 and 20 responses. For each switching-out COR the symmetrical pair was presented first followed by the other three in random order. The order for each animal is shown in Table 4.6. The criterion for a change of conditions was absence of consistent directional change in the numbers of responses made and time spent in each of the schedules over five consecutive sessions. For each animal coefficients of variation computed for each component with data from these 5 sessions did not exceed 0.20 for local response rates and 0.17 for CO rates. All other aspects of the procedure were the same as those in the first two experiments. In particular, concurrent VI 1-min schedules were again employed.

Patterns of local response and reinforcement rates were derived from data obtained by counting the number of seconds spent, responses made and reinforcers obtained in each of 6 bins. The first five of these summed events in

TABLE 4.6: The number of sessions for each condition and the distribution of reinforcers, responses and time between the stimulus-light-on (ON) and the stimulus-light-off (OFF) schedules and the number of changeovers made. The first number in each COR pair indicates the COR required for switching from the ON to OFF schedule, switching-into COR, the second the COR for switching from OFF to ON switching-out COR. The data are sums over the final three sessions of each condition.

Subject	COR pair	Sessions	Reinforcers		Responses		Time(secs)		Change-overs
			ON	OFF	ON	OFF	ON	OFF	
R3	5/5	16	129	127	1222	1292	2348	2685	708
	10/5	14	117	119	936	1022	1859	2108	477
	20/5	14	103	109	783	1041	1647	1965	293
	2/5	8	131	126	1335	1005	2633	2120	978
	10/10	5	123	118	1077	1013	2112	2114	390
	5/10	14	120	115	1035	836	1954	1621	552
	20/10	31	93	101	667	922	1364	1693	242
	2/10	33	119	117	1098	1134	1690	2003	560
R4	10/10	14	119	120	2808	3408	3368	3513	286
	20/10	20	102	117	3083	4872	2644	3852	158
	2/10	11	123	113	4838	3371	3726	2851	254
	5/10	24	120	117	3397	2879	3500	3045	288
	5/5	10	126	121	3569	3278	3618	3462	342
	2/5	8	130	124	4025	3060	4160	3492	399
	10/5	6	120	123	2565	4175	2928	4394	248
	20/5	51	103	88	2873	2486	3862	3033	118

successive 4-sec intervals of the first 20 secs of post-changeover time, while the last summed events following the first 20 secs of post-changeover time. Response and reinforcement rates were then calculated separately for each bin from sums over the last three days of each condition.

Results

In Table 4.6 are presented sums over the last three days of each condition of the number of changeovers and the numbers of responses, time and reinforcers associated with each schedule. In agreement with the results of the first experiment lower changeover rates are generally associated with higher switching-into and switching-out CORs.

In Figure 4.5 the proportions of responses, time and reinforcers in the stimulus-light off schedule have been plotted against the switching-into requirement for each animal under each switching-out COR (logarithmic scale). Except for the results of two conditions, the same general pattern as that shown in Figure 4.4 can be observed here. In 2/10 for R3 and 20/5 for R4 there was a sudden preference change for which the only explanation is the age of the animals. Each of these conditions was the last presented to the respective animals. Both were at this time showing considerable signs of aging as well as increased between-session variability in behaviour.

The ratio of local response rates is plotted against the variable COR value (logarithmic scale) in Figure 4.6. The same general pattern as that found in the second experiment is evident here. That is, local response rate

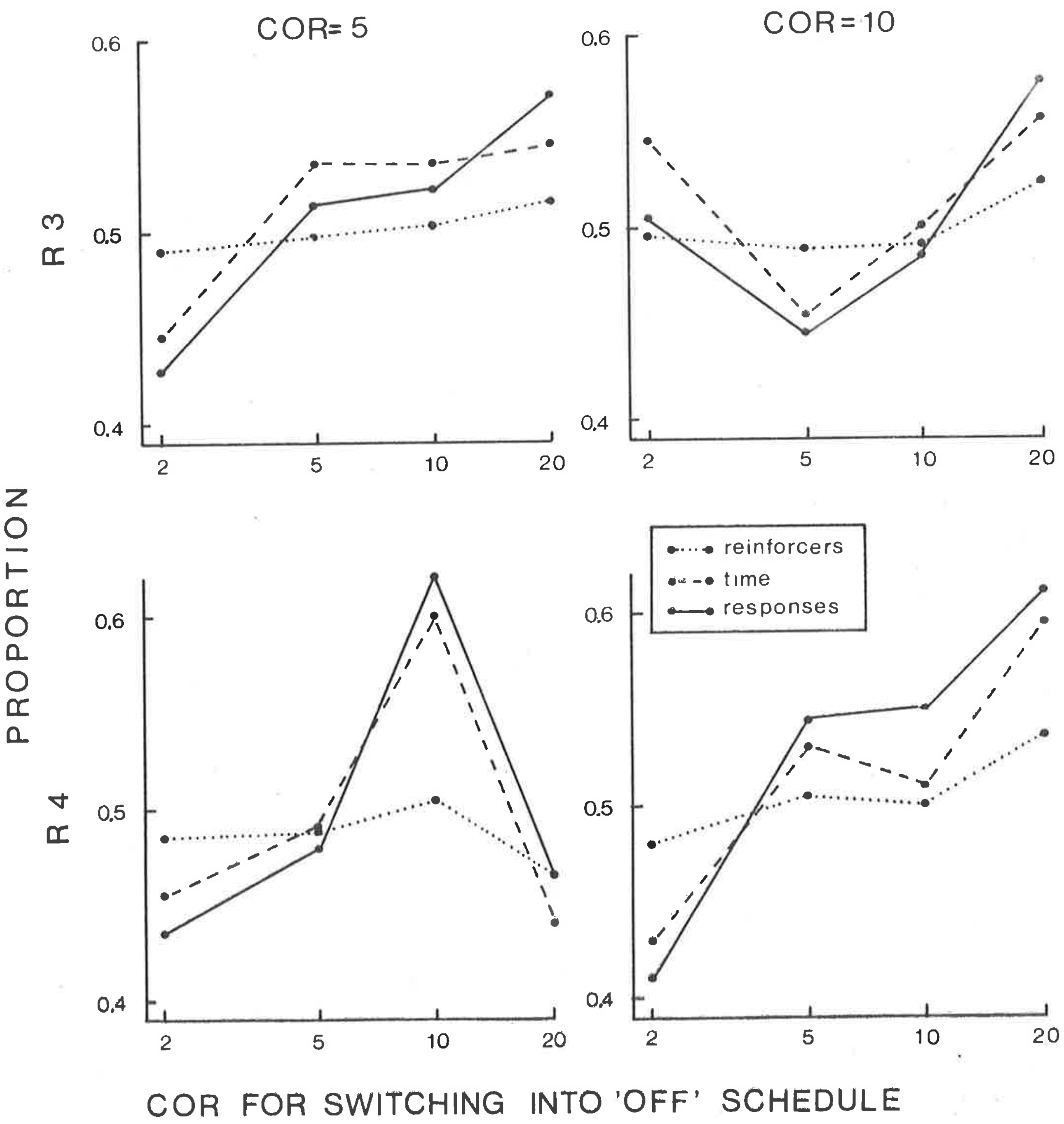

FIGURE 4.5: The proportion of responses, time, and reinforcers associated with the stimulus-light-off schedule as a function of the COR required for switching into that schedule (logarithmic scale). The rows correspond to the subject from which the data were obtained and the columns to the different CORs required for switching out of that schedule.

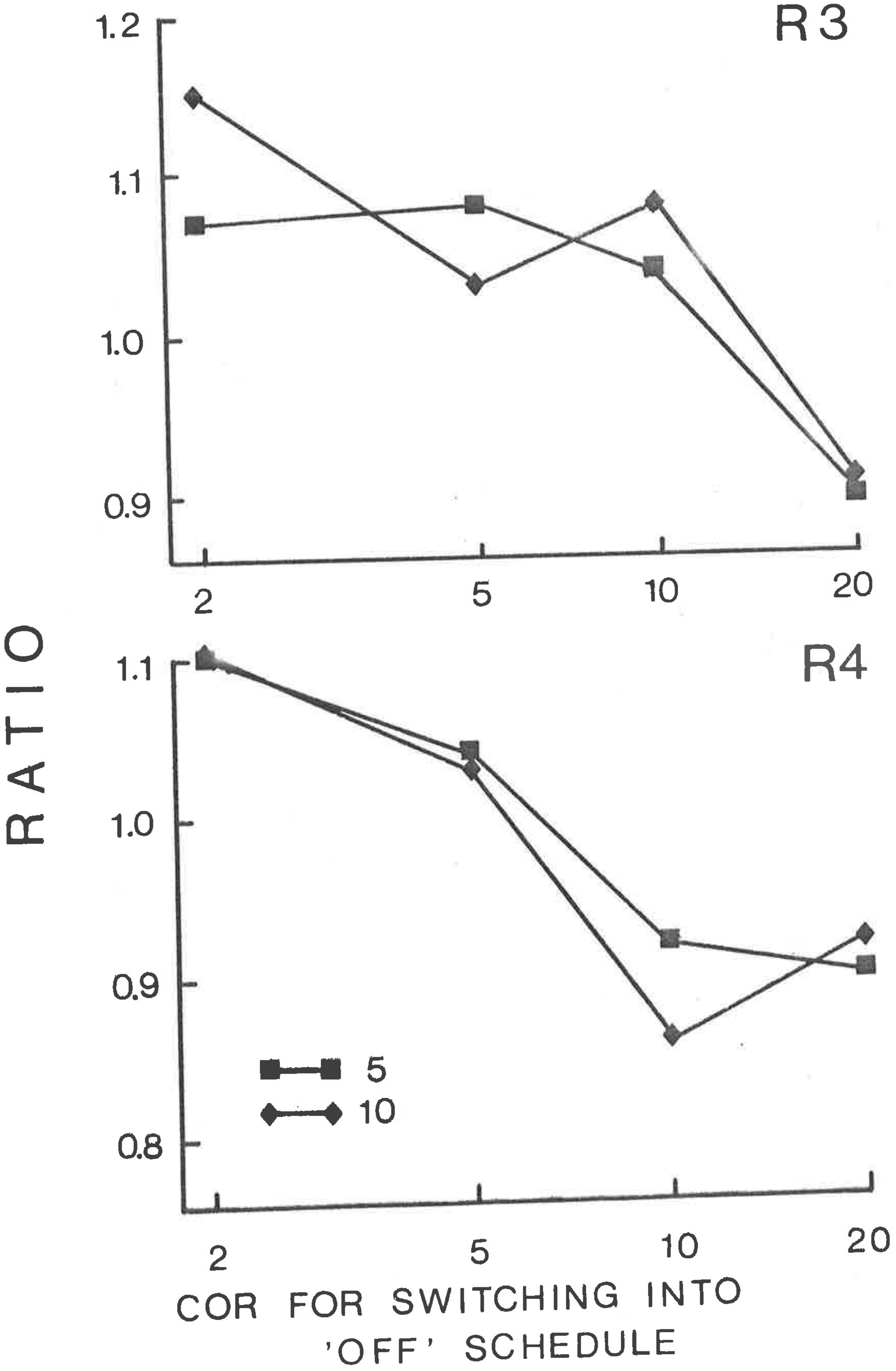

FIGURE 4.6: The ratio of local response rates (rate of responding when the stimulus-light was on divided by the rate when it was off and house-lights were on) as a function of the COR required for switching into the stimulus-light-off state (logarithmic scale). For each subject ratios were independently derived for the two switching into stimulus-light-off COR values (5 and 10 responses).

tended to be greater in the schedule associated with the larger switching-into COR and the difference in local rates increased with the difference in the two CORs.

Figure 4.7 presents the pattern of local reinforcement rate for each condition, grouped according to subject and switching-out COR. For all conditions a high rate in the first 4 secs is followed by a much lower rate which remains relatively constant. Excepting the case of R4 with a switching-out COR of 10, the reinforcement rate in the first 4 secs following a changeover increased as the switching-into COR became greater.

Patterns of local response rate are presented similarly in Figure 4.8. In three of the four sets of data the highest rate in the first 4 secs is associated with the lowest switching-into COR, although in each case the difference between the four values is relatively small. Thus there is no differential in immediate post-changeover response rates which can be attributed to the corresponding reinforcement rates. The two animals showed different patterns of change in response rate with post-changeover time. R3 exhibited a high initial rate followed by a decline, and in most instances response rate then increased. The response rate of R4 generally increased with post-changeover time. For both animals the tendency to exhibit a relatively high rate after 20 secs of post-changeover time was most pronounced following the larger switching-into CORs, particularly when the requirement was 20 responses.

Discussion

Unfortunately the data here are not directly comparable with those obtained by Pliskoff _et al_ (1978). They recorded

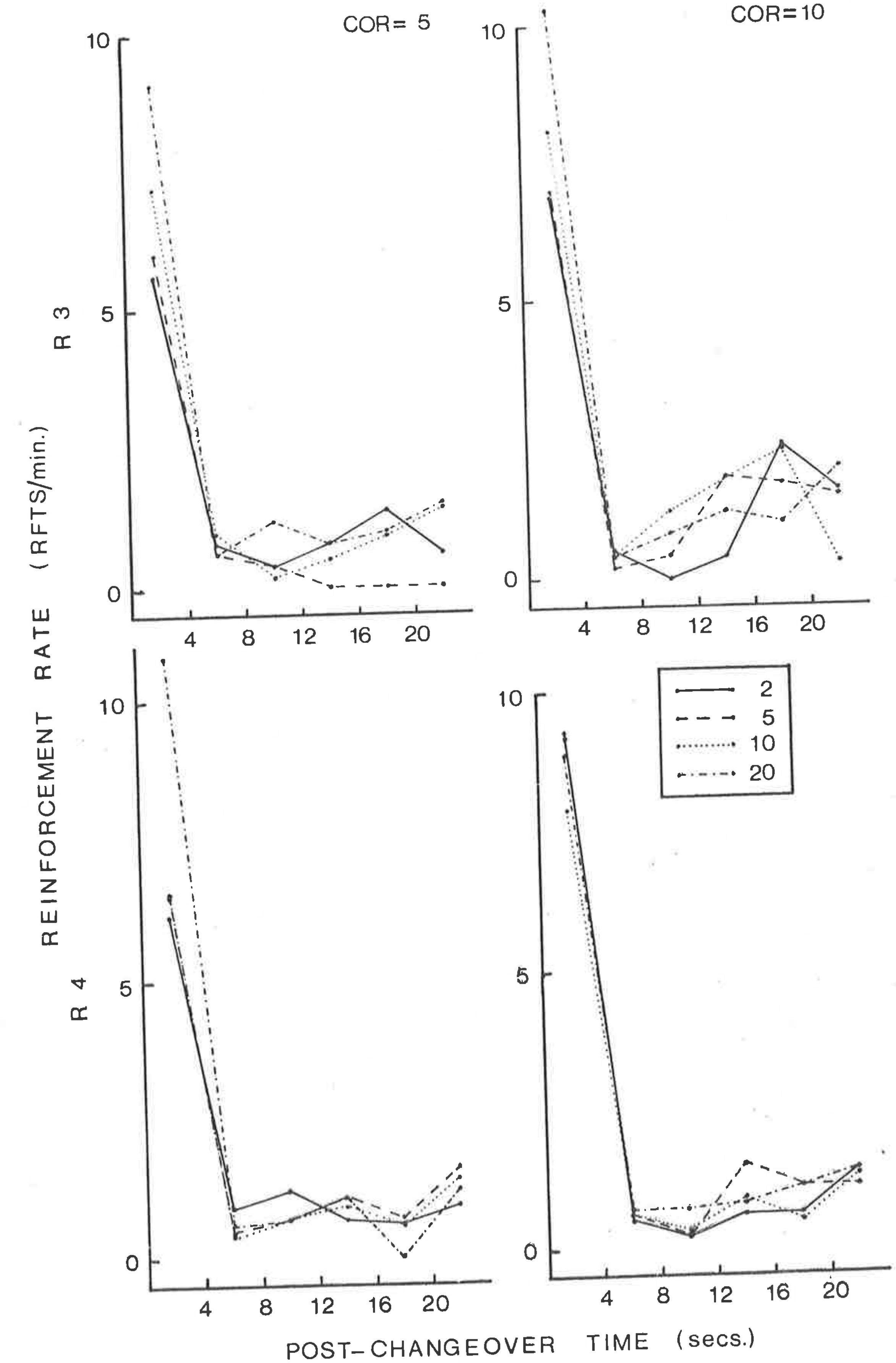

FIGURE 4.7: Local reinforcement rate in the stimulus-light-off schedule as a function of post-changeover time. The rows correspond to the subject from which the data were obtained and the columns to the different CORs for switching out of that schedule. The legend indicates the COR for switching into that schedule.

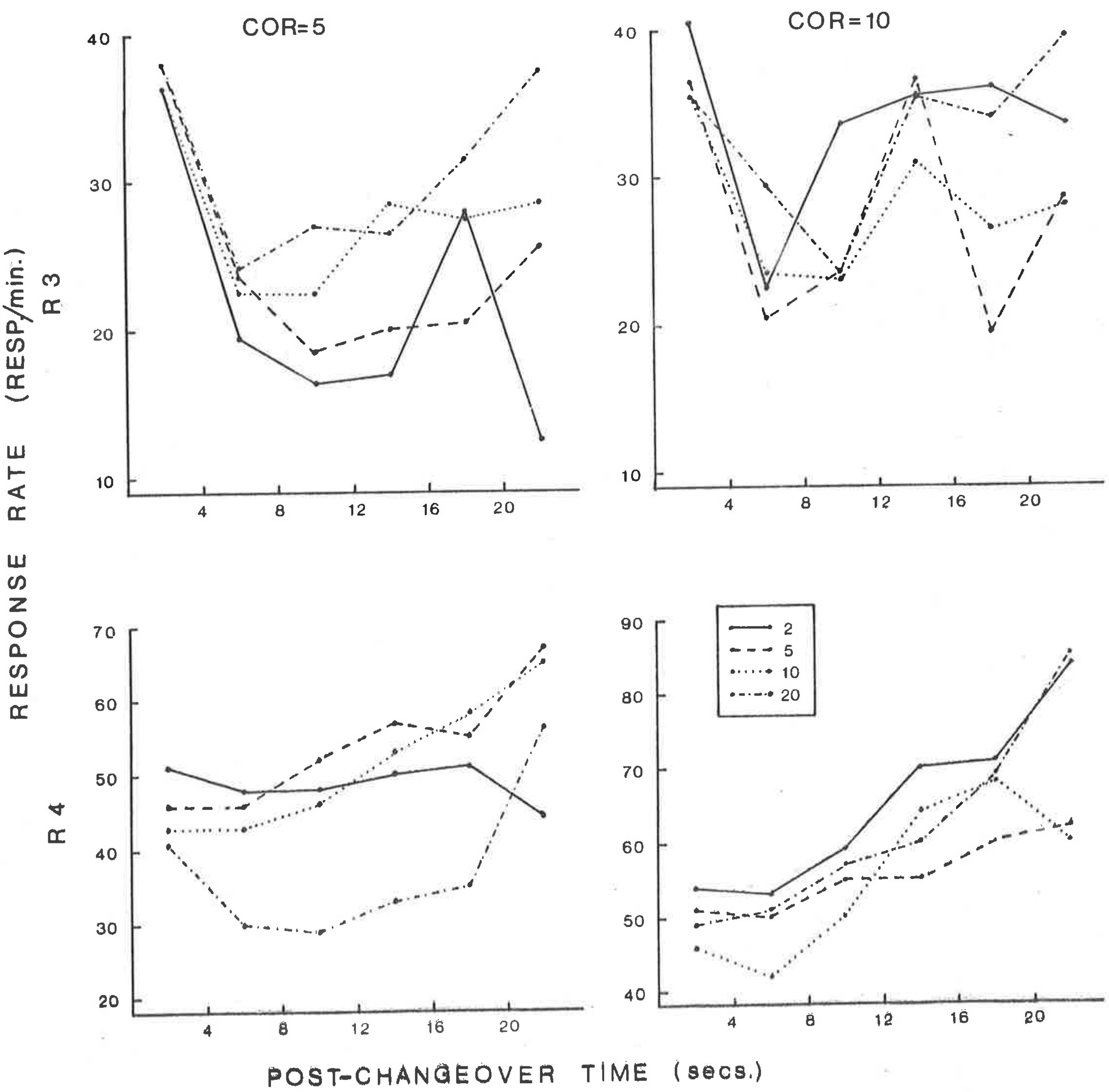

FIGURE 4.8: Local response rate in the stimulus-light-off schedule as a function of post-changeover time. The rows correspond to the subject from which the data were obtained and the columns to the different CORs for switching out of that schedule. The legend indicates the COR for switching out of that schedule.

local response rates only in the first 5 secs after each changeover. However, their results do suggest that response rate will be higher in the first than in the second two second post-changeover period. The data collected here were originally in 2-sec bins but these were collapsed for clarity. Inspection of the original data showed that while R3 had a higher response rate in the first 2 secs, R4 exhibited a higher rate in the second. The only contrary instance was the COR pair 20/10 for R3 where response rate was higher in the second two seconds of post-changeover time. Thus the evidence from this experiment neither supports nor refutes the hypothesis that the post-changeover response rate pattern obtained by Pliskoff _et al_ applies also when VI times are not halted during changeovers.

It can be concluded from the results of this experiment that the greater local response rate associated with the schedule with the larger switching-into COR, observed in both Experiments 2 and 4, was not due to greater response "bursts" following longer CORs. The elevated response rate which has been observed during CODs (e.g. Silberberg and Fantino, 1970) was not found to occur following CORs. In most instances the initial post-changeover rate was at least matched by response rates at longer post-changeover times.

From this and the first three experiments it can be concluded that an increase in one or both CORs produces a decrease in changeover rate and an increase in local response rate. If only one COR is increased the extra time and responses are apportioned more to the schedule with the larger switching-into COR. This appears not to be solely a result of changes in local reinforcement rate but may be due in part to the COR acting as an aversive stimulus, affecting the behaviour which precedes the changeover. This differential depressive effect does not arise when symmetrical CORs are employed.

It is possible that the higher local reinforcement rate immediately following the larger COR may direct preference to that schedule, even though this preference is not reflected in immediate post-changeover response rate. Results from this experiment showed that differences in local response rate produced by variations in COR size were principally a result of differences arising after long post-changeover times. Even allowing for this discrepancy it is difficult to account for the results of the third experiment in terms of local reinforcement rates. A pattern of increasing local response rate with post-changeover time may explain the response preference observed in the third experiment, but it was the schedule with the lower local reinforcement rate which maintained the higher local response rate. Thus there are difficulties associated with an account relying solely on local reinforcement rates, and it seems necessary to invoke the aversive properties of COR size to give a complete explanation.

4.6. EXPERIMENT 5

Silberberg and Fantino (1970) showed that if post-COD responses only were considered, overmatching described the relation between response and reinforcement ratios. With COD responses included matching was obtained. The results of Experiment 4 suggest that responding following a changeover in which the requirement was the completion of a number of responses most closely resembles post-COD responding. That is, there is little bursting of responses.

Two implications follow from this similarity. Firstly, it is unlikely that the high probability of reinforcement immediately after a changeover is responsible for the elevated response rate during COD. The same high probability exists following completion of a COR yet no bursting occurs. It therefore seems more likely that the elevated COD response rate reflects the zero probability of reinforcement during that period. Such an hypothesis needs to be explored further.

The second implication is that we would expect to find overmatching when CORs rather than CODs are employed. If the patterns of responding and reinforcement following CODs and CORs are similar the function describing the relation between relative response and reinforcement rates should also be similar. Evidence described earlier suggests that this is the case. When CORs are used deviations from matching are almost invariably in the direction of overmatching. However, this may be strongly influenced by whether VI timers are interrupted by changeovers or not.

This experiment explored this possibility further by employing a design similar to that of Shull and Pliskoff (1967) in their investigation of the effects of COD duration on matching: relative reinforcement rate was fixed at 0.75 and COR size was varied. As in the four previous experiments VI timers could continue to operate during changeovers.

Method

Subjects. Two male Wistar hooded rats, experimentally naive and approximately 5 months old at the commencement of the experiment were maintained on a 23-hour food deprivation cycle. Housing was in individual cages with free access to water.

Apparatus. The apparatus was the same as that used in previous experiments.

Procedure. Preliminary training consisted of exposure to a continuous reinforcement schedule for one session followed by 23 sessions of exposure to a VI 1-min schedule. Sessions were of 60 min duration throughout, and were run 7 days a week.

Each of the conditions was then presented in the order shown in Table 4.7 for the indicated number of sessions. The basic schedule was a concurrent VI 1-min VI 3-min. Each condition was terminated when the coefficients of variation for (R1/R2)|(r1/r2), (T1/T2)|(r1/r2) and the changeover rate, calculated over five consecutive sessions, did not exceed 0.15. A limit of 40 sessions was imposed, but this was reached only once without the criterion being satisfied (R1B2, COR=4).

All other aspects of the procedure replicate those of Experiments 1, 2 and 4.

Results

In Table 4.7 are shown the distributions of responses and time between the alternatives, the number of reinforcers obtained from each and the number of changeovers made. Overall response rate showed some change over the course of the experiment. It was relatively low with CORs of 1 or 2 responses but then increased suddenly when the COR was

TABLE 4.7: The distributions of reinforcers, responses and time between the VI 1-min and VI 3-min schedules, and the number of changeovers made. The data are sums over the final five sessions of each condition. The total number of sessions each condition was in operation is indicated. 'Prop' denotes the proportion of responses time or reinforcers for the VI 1-min schedule.

			Reinforcers			Responses			Time (secs)			
Subject	COR	Sessions	VI-1	VI-3	Prop	VI-1	VI-3	Prop	VI-1	VI-3	Prop	Changeovers
R1B1	1	11	263	89	.75	7516	6192	.55	10190	7800	.57	1878
	2	31	247	85	.74	5184	2779	.65	8016	4556	.64	1281
	4	37	255	82	.76	14568	4411	.77	10204	3823	.73	504
	6	10	237	82	.74	11121	3932	.74	9669	4047	.70	388
	8	17	226	69	.77	13329	3188	.81	10804	3068	.78	203
	4	26	264	81	.77	14542	3886	.79	11230	3575	.76	402
R1B2	1	16	265	89	.75	5667	3957	.59	10479	7521	.58	1418
	2	9	260	87	.75	6616	2667	.71	9030	4304	.68	1152
	4	40	268	91	.75	13421	2100	.86	11376	2700	.81	718
	6	9	259	81	.76	11124	2636	.81	9808	3040	.76	670
	8	40	269	46	.85	16521	1278	.93	13212	1355	.91	216
	6	20	274	52	.84	16010	910	.95	13231	1351	.91	299

increased to 4 responses. This higher level was approximately maintained through the remaining conditions. Since the conditions with COR=1 or 2 were not repeated, it is not clear whether this was a direct effect of COR size or a practice effect. It seems likely that both factors were involved.

Changeover rate is plotted for each animal against COR size in Figure 4.9. In this and the remaining figures the result from the repeated condition (COR=4 for R1B1 and COR=6 for R1B2) is indicated by a point not connected with the others. The relation shown is similar to that obtained in the earlier experiments, with changeover rate decreasing in an exponential fashion as the COR is increased.

The proportions of time, reinforcers and responses in Table 4.7 are plotted in Figure 4.10. The proportion of reinforcers obtained from the VI 1-min schedule remained approximately constant at about 0.75 throughout for R1B1 but was substantially greater when R1B2 was exposed to COR=8 and the re-exposure to COR=6. In these instances response and time proportions were greater than 0.90. Clearly the small amount of time and responses allocated to the VI 3-min schedule substantially reduced the number of reinforcers obtained from it.

Both subjects show clear undermatching of both time and response ratios to reinforcement ratios with CORs of 1 and 2 responses. For R1B1 matching was closely approximated when the COR was 4 and 6 responses, more so for response than time. This changed to slight overmatching with COR=8. R1B2 showed overmatching over the range COR=4 to COR=8, except that on the first exposure to COR=6 the time ratio matched the reinforcement

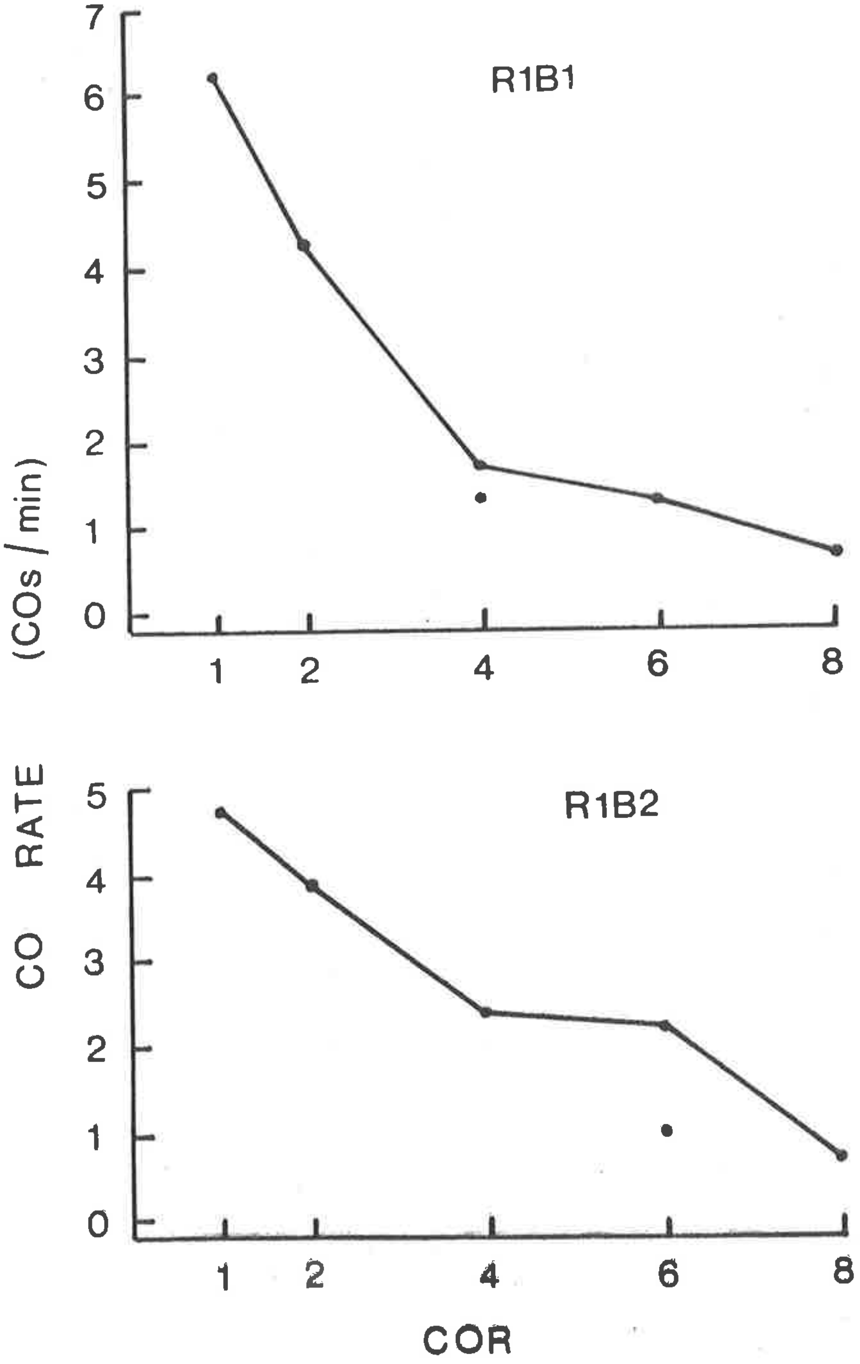

FIGURE 4.9: Changeover rate as a function of COR size.

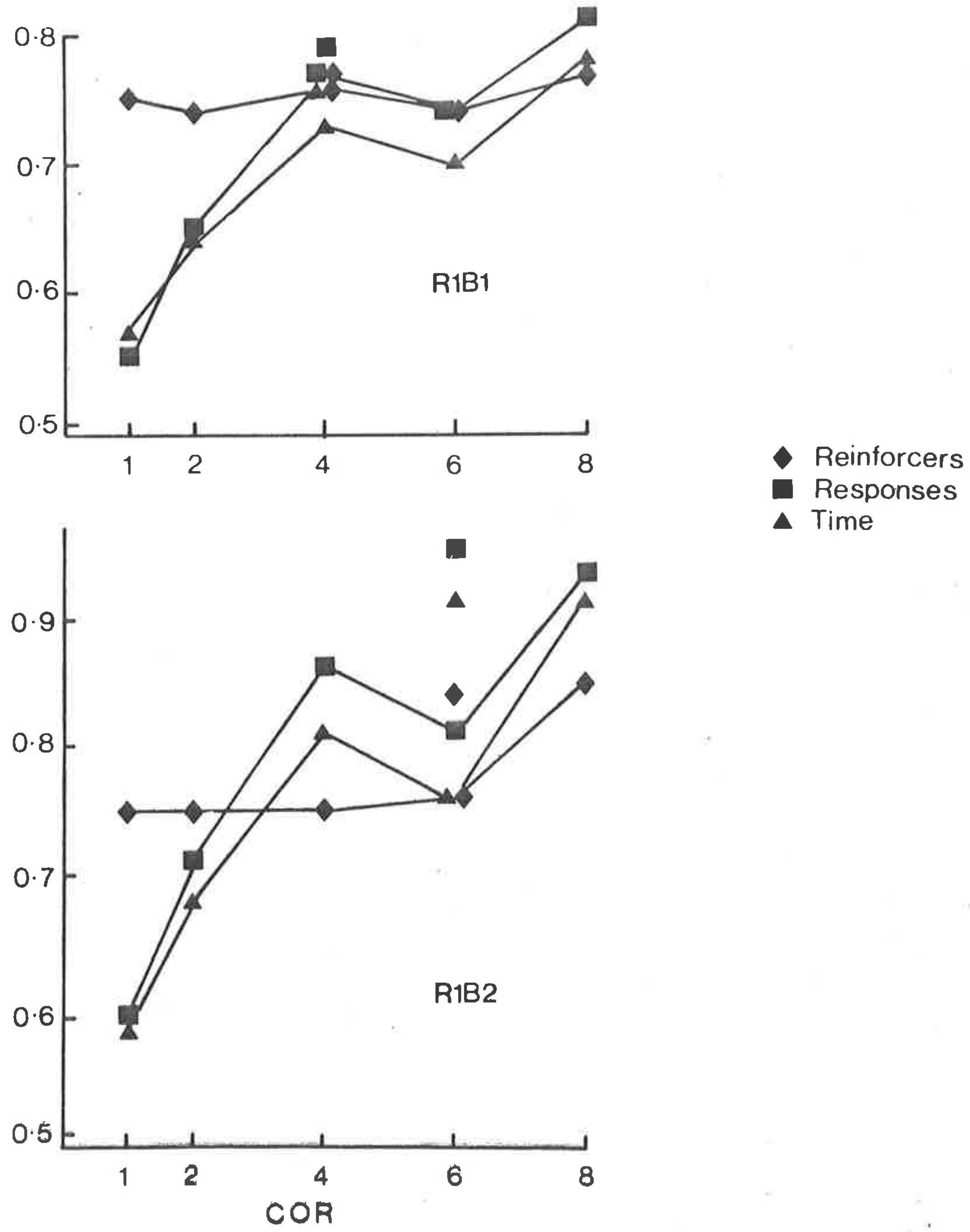

FIGURE 4.10: The proportion of responses, time, and reinforcers associated with the VI 1-min schedule as a function of COR size.

ratio. Behaviour under the re-exposure to COR=6 did not differ much from that recorded with COR=8, suggesting that the effects of exposure to this latter condition had not disappeared when exposure to COR=6 had terminated.

For both animals response ratios tended to be greater than time ratios. The magnitude of the difference was only small with COR=1 or 2 responses, and the one contrary instance was R1B1's exposure to COR=1. The difference in ratios indicates a tendency to respond faster in the VI 1-min schedule. This is illustrated more clearly in Figure 4.11 where the ratio of local response rates (rate in VI 1-min/rate in VI 3-min) is plotted against COR size. For R1B1 the ratio rose as the COR was increased from 1 to 4 responses and was approximately constant thereafter at about 1.20. The picture is more complicated in the case of R1B2, where the greatest ratios were found with COR=4, particularly on re-exposure. However, the same rise through CORs 1, 2 and 4 is evident in the data from this subject.

Discussion

The results clearly indicate that a range of relations between response and time ratios and reinforcement ratios, from undermatching to overmatching, may be obtained according to the size of the COR. Both subjects showed undermatching with CORs of 1 and 2 responses, with R1B1 closely approximating matching at larger values and R1B2, overmatching. The undermatching obtained contradicts earlier studies: Stubbs and Pliskoff (1969) found matching with COR=1 and Guilkey *et al* (1975) matching or overmatching with COR=2. However, both

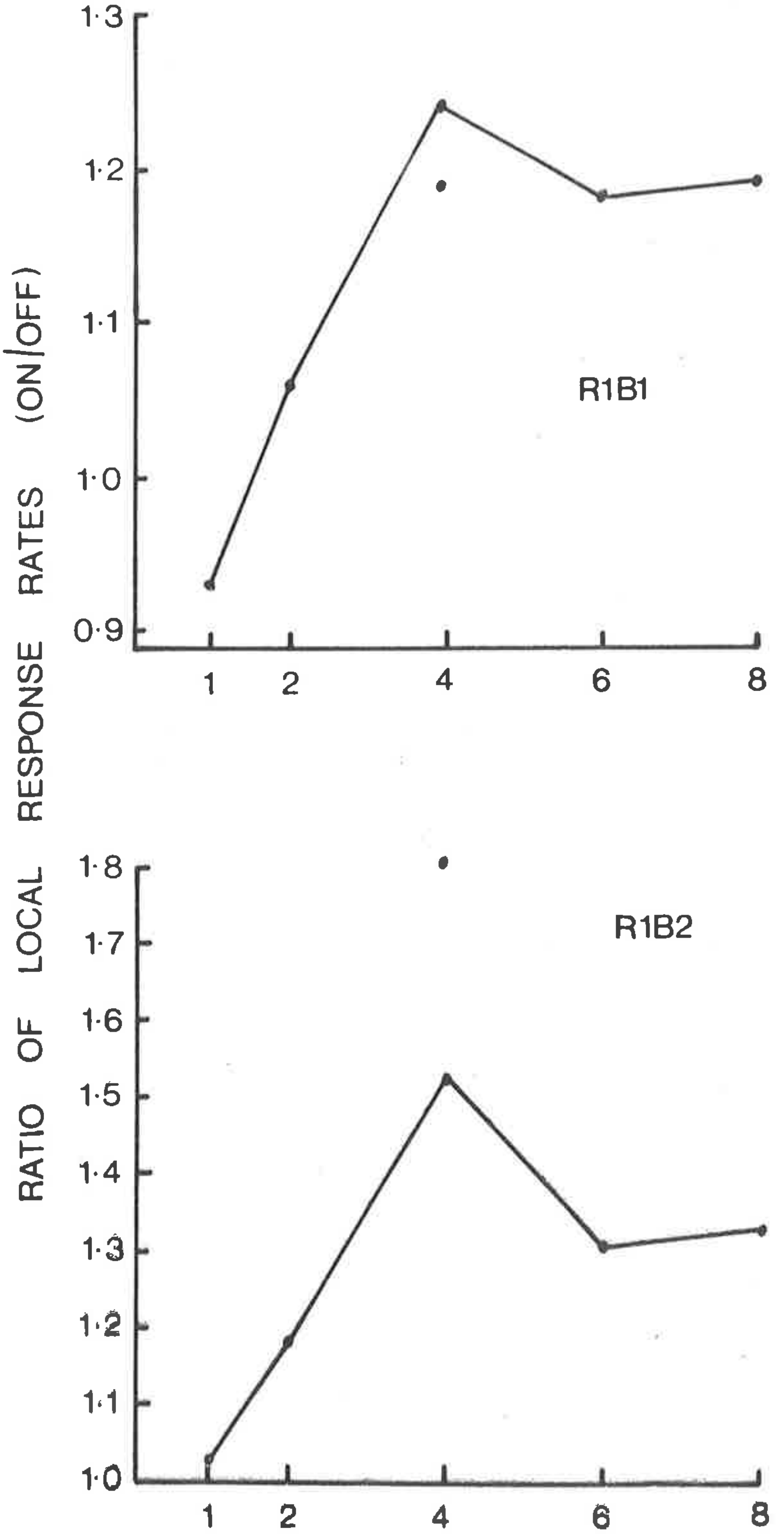

FIGURE 4.11: The ratio of local response rates (rate of responding in the VI 1-min schedule divided by the rate in the VI 3-min schedule) as a function of COR size.

of these studies halted VI timers during changeovers. The overmatching at higher COR values in this experiment accords with the results of other studies employing larger COR values.

It has been a consistent finding in studies employing the COR that response ratios tend to be greater than time ratios so that the former overmatch the reinforcement ratios to a greater degree. This was confirmed in this study, but, in addition, when subjects were matching or undermatching, response ratios generally exceeded time ratios. As revealed in Figure 4.11, local response rate was, with a single exception, faster in the schedule yielding the higher reinforcement rate. Such a result is directly opposite to that almost invariably found when a COD is employed (see Section 2.4.2).

Silberberg and Fantino's (1970) data make it difficult to decide whether post-COD responding is generally higher in the schedule yielding the higher reinforcement rate. There was considerable inter-subject differences and the issue is complicated by the fact that post-COD response rate on the lower valued schedule was artificially inflated by the continuation of bursting after the COD had terminated. Responding following completion of a COR and after a COD has elapsed could be seen to be more similar if it were shown that post-COD responding was greater in the richer schedule.

4.7. SUMMARY AND IMPLICATIONS

Experiments 2 and 4 demonstrated that the COR cannot merely be regarded as a means for maintaining the independence of concurrent operants. If the two CORs in a concurrent VI VI schedule are independently varied their size can profoundly affect the distribution of responses and time between the schedules. This effect is not due to COR size influencing relative reinforcement rates but is a property of the COR itself. Thus, while the COR is not a parameter of reinforcement, an equation purporting to describe the distribution of responses between the alternatives, such as the matching relation, should include COR size if it is to be regarded as complete.

In Chapter 2 it was shown that variables such as magnitude and immediacy of reinforcement should be included in a general matching relation. If we include COR size in the same manner we can write

$$\frac{R_1}{R_2} = f_1\left(\frac{COR_{21}}{COR_{12}}\right) f_2\left(\frac{r_1}{r_2}\right) \tag{4.3}$$

with all variables other than reinforcement rate and COR size equal across the alternatives. COR_{21} denotes the COR for switching from schedule 2 to schedule 1, and <u>vice versa</u> for COR_{12}. The nature of f_2 has been extensively discussed in Chapter 2, and for present purposes it will be sufficient to assume matching, i.e. f_2 is the identity function.

Since power functions have previously been found to closely approximate the relation between response and reinforcement variables, we may assume f_1 a power function as a first approximation. We can then rewrite Equation 4.3 as

$$\left(\frac{R_1}{R_2}\right) \Big/ \left(\frac{r_1}{r_2}\right) = c\left(\frac{COR_{21}}{COR_{12}}\right)^d \tag{4.4}$$

As before the parameters c and d must be empirically derived, and c is a measure of the bias to one alternative or the other. If d is equal to 1.0 subjects are matching their response allocation (modified to account for any differences in reinforcement rate) to relative COR size. Thus, if the COR ratio is 2.0, twice as many responses and twice as much time will be allocated to schedule 1, with the larger switching-into COR. Similarly, if d is less than 1.0 the response ratio is not as extreme as the COR ratio, and if it is more than 1.0, the response ratio is more extreme.

Equation 4.4 was applied to the data of Experiment 2, where $COR_{12} + COR_{21} = 10$, but the ratio COR_{21}/COR_{12} varied across the range 0.11 to 9.0. The results are presented in Table 4.8 together with those from fitting the time allocation version of Equation 4.4. There is some bias to schedule 1, but this is not particularly strong in any instance. Under-matching of response and time ratios to COR ratios is evident in the data from all subjects. While differences in the two CORs influenced response and time allocation, response and time ratios were much closer to indifference than the COR ratios.

The proportion of variance in the response and time ratios accounted for by Equation 4.4 was reasonably high, 0.90 or over in half of the cases. This proportion may have been greater if we had not assumed matching but fitted a power function to the reinforcement ratio as well. However, in Experiment 2 no attempt was made to directly influence the distribution of reinforcements across the alternatives, and the "naturally" occurring variation was very small. Because of this an accurate value for the reinforcement ratio exponent

TABLE 4.8: Fits of Equation 4.4 to the data of Experiment 2 using both response ratios and time rations. *c* and *d* are the two parameters and r^2 the proportion of variance accounted for by the equation.

	Response Ratios			Time Ratios		
Subject	c	d	r^2	c	d	r^2
R1	1.16	0.37	0.88	1.12	0.26	0.86
R3	1.00	0.28	0.88	0.97	0.22	0.90
R4	1.10	0.23	0.92	1.13	0.18	0.93

could not have been obtained. A more complete experimental investigation of Equation 4.3 would include variations in both reinforcement and COR ratios.

If the values of d obtained using response ratios are compared to those obtained with time ratios it can be seen that the degree of undermatching is greater for time than responses. This implies that the schedule to which more time is allocated will also have the faster response rate. This point can be demonstrated mathematically. For simplicity we will assume that there is no bias and that reinforcement rates are equal across the two alternatives. We then have the two relations

$$\frac{R_1}{R_2} = \left(\frac{COR_{21}}{COR_{12}}\right)^{x} \quad \text{and} \quad \frac{T_1}{T_2} = \left(\frac{COR_{21}}{COR_{12}}\right)^{y}$$

$$\text{where} \quad x > y$$

Therefore

$$\frac{COR_{21}}{COR_{12}} = \left(\frac{R_1}{R_2}\right)^{1/x} = \left(\frac{T_1}{T_2}\right)^{1/y}$$

$$\text{and} \quad \frac{R_1}{T_1} = \left(\frac{T_1}{T_2}\right)^{\frac{x}{y}-1} \frac{R_2}{T_2}$$

where R_1/T_1 and R_2/T_2 are the local response rates in schedules 1 and 2 respectively. Now $(T_1/T_2)^{x/y-1} > 1$ if and only if $T_1 > T_2$. Thus if more time is allocated to schedule 1, local response rate in schedule 1, (R_1/T_1), will be greater than local response rate in schedule 2, (R_2/T_2).

This statement about a general property of concurrent performance with CORs as the changeover contingency unites results from Experiments 2, 4 and 5. In the first two of these preference for one schedule over another was modified by varying the sizes of the two CORs, and it was found that local response rate was greater in the schedule to which more time was allocated (compare Figures 4.3 and 4.4 in Experiment 2 and 4.5 and 4.6 in Experiment 4). In Experiment 5 preference was directed by employing VI schedules of different value for the two alternatives and local response rate was almost invariably faster in the alternative with the more lucrative VI schedule (Figure 4.11) to which more time was allocated (Figure 4.10).

Experiment 4 also presented some information as to the basis of this local response rate differential in the patterns of local response rate (Figure 4.8). R4 showed a strong tendency to increasing response rate with longer post-changeover times. Thus the more time that is allocated to an alternative, the greater will be the mean local response rate. The picture is not so clear for the data obtained from R13, but in most instances there is a tendency for response rate to rise after 10 secs of post-changeover time.

In Experiment 1 it was found that local response rate increased with increases in the symmetrical CORs. However, time allocated to responding on the two schedules (as opposed to time spent switching) did not increase with increases in COR size, as would be expected from the above hypothesis. However, if we rephrase the hypothesis and state that local response rate increases with mean inter-changeover time the results from Experiment 1 clearly concur. The total time allocated to an alternative is equal to the mean inter-changeover time for that alternative multiplied by the number of changeovers from that alternative. The original hypothesis was derived from Experiment 2, where changeover rate was approximately constant, so that mean inter-changeover time and total time allocation could not be separated.

Thus the results from Experiments 1, 2, 4 and 5 concur with the hypothesis that local response rate in an alternative increases with the mean inter-changeover time for that alternative. In addition, results from Experiment 4 suggested that the basis for this may be in a tendency to high response rates after long post-changeover times. The results of Experiment 3 agree, but in this instance the preferred schedule neither provided a higher reinforcement rate nor had a higher switching-into COR. Preference was based simply on the fact that increased time allocation caused an increase in the size of the switching-out COR. Thus the local response rate difference need not be dependent on a difference in local reinforcement rates.

4.8. CONCLUSIONS.

Concurrent performances differ notably according to whether a COD or COR is employed as the means of maintaining the independence of the operants. In particular, preference is directed to the schedule with the larger switching-into COR value, and local response rate is greater in the schedule with the larger mean inter-changeover time. In concordance with this, it was found that if reinforcement rates differ across the schedules, response ratios show a greater degree of preference for the more lucrative schedule than time ratios. In addition, matching is not reliably found across a range of COR values as it is across a range of COD lengths. The reason for this and the degree of similarity between concurrent responding with CORs employed and post-COD responding remain to be fully researched. The generality of matching is strongly questioned by the differences in concurrent performances with the two different changeover contingencies.

CHAPTER 5

BEHAVIOURAL CONTRAST

5.1 DEFINITIONS

Multiple schedules consist of two or more component schedules whose operation is indicated by discriminative stimuli. Each discriminative stimulus signals one reinforcement contingency. Of particular interest are the interactions between components: by holding one schedule constant and varying the other we can examine the effects on the behaviour in the unchanged component of the modification to the other schedule. Such interactions are customarily defined in terms of the response rates maintained by each of the schedules. They fall into two types, according to whether the effects are seen in the overall response rate maintained by the component schedule or in the local response rate pattern. Accordingly, the following definitions will be used: (see also Table 5.1).

1. If the changed component maintains a lower rate of responding because of the alteration to the schedule then
    (a) an increase in response rate in the unchanged component is termed positive (behavioural) contrast
    and (b) a decrease in response rate in the unchanged component is termed negative induction.
2. If the changed component maintains a higher rate of responding because of the alteration to the schedule then
    (a) an increase in response rate in the unchanged component is termed positive induction
    and (b) a decrease in response rate in the unchanged component is termed negative (behavioural) contrast.
3. If the immediately prior component maintains a lower overall response rate then

(a) an elevation in response rate in the beginning of the component is termed local positive contrast

and (b) a depression in response rate in the beginning of the component is termed local negative induction.

4. If the immediately prior component maintains a higher overall response rate then

    (a) an elevation in response rate in the beginning of the component is termed local positive induction

    (b) a depression in response rate in the beginning of the component is termed local negative contrast.

These definitions may be made clearer by considering the most common method of demonstrating multiple schedule interactions: change from multiple VIxVIx to multiple VIxEXT and back to multiple VIxVIx. Since VI schedules produce a relatively constant response rate, local response rate will not vary within the components of multiple VIxVIx, thus providing a good baseline for assessing any local contrast or induction effect In addition, the use of extinction ensures a considerable change in response rate in that component.

Contrast effects are illustrated in Figure 5.1. The A to B transition shows positive contrast and the C to D transition negative contrast. Clearly if baseline is recovered following a demonstration of positive contrast, negative contrast will also be observed, and vice versa. If negative contrast was not observed (i.e. if response rate at D was the same or greater than that at B and C) then the A-B rate increase could be attributed simply to a longer length of exposure to the unchanged VI schedule. As Rachlin (1973) has noted, this suggests that positive and negative contrast may exemplify the same phenomenon.

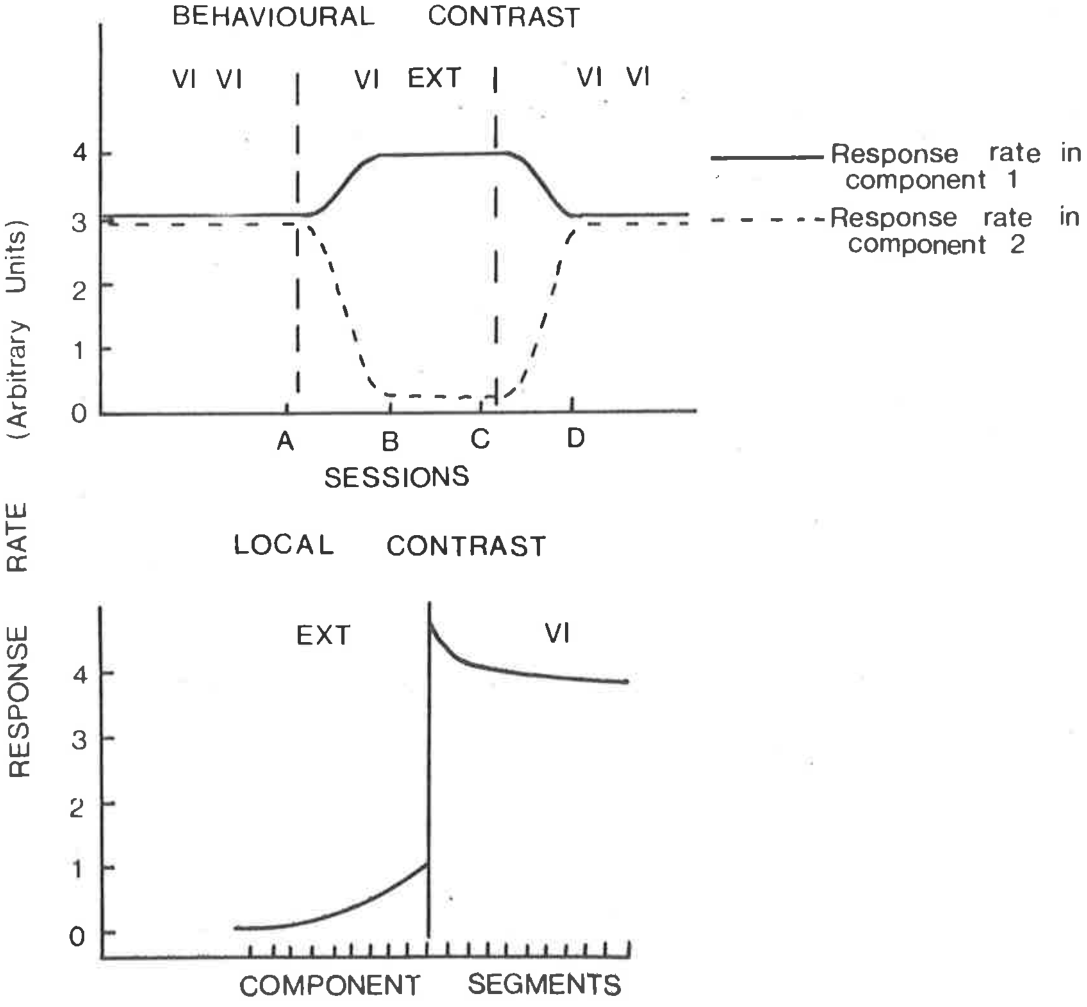

FIGURE 5.1: Diagrams illustrating changes in overall response rate characterizing positive and negative behavioural contrast, and changes in local response rate characterizing local positive and local negative contrast. See text for explanation.

Local contrast effects which may be observed when multiple VI EXT is in operation are also shown in Figure 5.1. Response rate is initially depressed in the EXT component following transition from the VI, but then increases (negative local contrast) while VI response rate is initially high preceding a decrease (positive local contrast). It is important to note that local and overall contrast effects are logically independent. However, contrast may be solely due to a change in response rate early in the VI component, so that local and overall contrast reflect the same change in the pattern of responding in the VI component.

Induction effects could be illustrated similarly, but the emphasis in both current research and the experiments to be reported here is on contrast. The procedures required to produce contrast effects have been outlined more exactly, and contrast is of greater theoretical significance, with a number of rival accounts of the phenomenon. These will be discussed first.

TABLE 5.1

OVERALL EFFECTS

		Direction of response rate change in unchanged component	
		LOWER	*HIGHER*
Response rate in change component relative to rate in unchanged component	*LOWER*	*NEGATIVE INDUCTION*	*POSITIVE CONTRAST*
	HIGHER	*NEGATIVE CONTRAST*	*POSITIVE INDUCTION*

LOCAL EFFECTS

		Direction of response rate change during component	
		INCREASING	*DECREASING*
Response rate in prior component	*LOWER*	*LOCAL NEGATIVE INDUCTION*	*LOCAL POSITIVE CONTRAST*
	HIGHER	*LOCAL NEGATIVE CONTRAST*	*LOCAL POSITIVE INDUCTION*

5.2 RIVAL ACCOUNTS OF CONTRAST

A detailed review of the contrast literature will not be attempted here since a number of reviews, to be mentioned below, already exist. Rather, the principle theoretical positions will be outlined and the evidence for each discussed. Each will be compared with Herrnstein's account, which has been described in Chapter 2.

Reinforcement Frequency

As a result of his early research on contrast Reynolds (1961a, 1961b, 1961c, 1961d) proposed that the change in reinforcement rate in the altered component was responsible for the contrast effects observed in the unaltered component.

> "The frequency of reinforcement in the presence of a given stimulus, *relative to the frequency during all of the stimuli that successively control an organism's behavior*, in part determines the rate of responding that the given stimulus controls. A change in the relative frequency associated with one of several successive stimuli changes the rate of responding during that stimulus; an increase in relative frequency produces an increase in the rate of responding." (Reynolds, 1961a, p.70, his italics)

This hypothesis was supported by data which showed that changes in response rate did not affect rate in the unaltered component, while all of a number of means of reducing reinforcement rate were successful in producing contrast.

Such an account is in accord with the positions of both Catania (1969, 1973) and Herrnstein (1970). The equations derived by both authors may be considered formalizations of the hypothesis first proposed by Reynolds (1961a). The principal difference between the two is Catania's focus on inhibition as the mechanism of interaction. Thus positive contrast results from the removal of the inhibitory effect of reinforcements in the altered component on responding in the unaltered component. As noted in Chapter 2, the mathematical formalizations of Catania and Herrnstein are very similar.

Response Suppression

Terrace (1963a, 1963b) showed that when a discrimination was learned without errors (i.e. with few or no responses during the EXT component of multiple VI EXT) contrast failed to occur. He concluded that suppression of responding in one component was necessary for contrast to occur in the other, unaltered component. While his initial emphasis was on the reduction in response rate as the controlling variable, Terrace (1972) has more recently suggested that response rate reduction is sufficient but not necessary for contrast to occur:

> "Contrast could be defined simply as an increase in the strength of the response to S^+ that results from alternating S^+ with an inhibitory stimulus."
>
> (Terrace, 1962, p.255)

Response Suppression vs Reinforcement Frequency

A number of attempts have been made to separate the effects of response rate and reinforcement rate reduction. In the usual paradigm for demonstration of contrast these two are perfectly confounded. A proper test requires that the changes made to one schedule preserve the constancy of one while varying the other. Attempts at this have included adding electric shock (e.g. Brethower and Reynolds, 1962), changing the schedule to DRL or DRO (e.g. Weisman, 1969) and changing the schedule to VT (e.g. Halliday and Boakes, 1972). Most of these studies have been reviewed in detail by Freeman (1971).

Conclusions are difficult to make from this body of research, not least because of methodological difficulties and contradictory results. However, the experiments show that both response rate and reinforcement rate reduction can produce contrast in the unaltered component, but that neither account is able to provide a complete explanation. Some alternative hypothesis is required if a statement of the necessary conditions for contrast is to be made. One possible candidate will be discussed: that contrast results from a change in the overall value of the altered component. That is, positive contrast occurs when the altered component becomes more aversive, negative contrast when it becomes more reinforcing.

Contrast and Preference

The views of both Terrace and Reynolds can be seen to converge if the concept of reinforcement is generalized from that used by Reynolds. Clearly, if electric shock is added to one component the value of that component (the algebraic sum of reinforcers and punishers associated with it) will decline. A generalized reinforcement rate reduction hypothesis would therefore predict contrast in the unaltered component. Similarly, since the added shock will also suppress responding, contrast would be expected on the basis of Terrace's hypothesis. But schedules themselves may be more or less aversive, so that the reinforcement account must also consider the relatives values of the schedules involved. For example, a change from a VI to a DRL schedule which arranges the same reinforcement rate is likely to increase the aversiveness of that component, since VI schedules are preferred over DRL schedules (Fantino, 1968).

The hypothesis that a change in a component's value is the necessary condition for contrast has been proposed by Bloomfield

(1969) and Premack (1969), but has received relatively little attention. One difficulty is that the same data which yielded contradictory conclusions in separating response suppression from reinforcement reduction must be used to evaluate this hypothesis. While much of the data are supportive, some remain contradictory. In addition, independent evidence is needed on animals' relative preference for the different conditions experienced in the altered component, and such evidence is not always available.

In terms of Herrnstein's (1970) equation this account suggests that positive contrast occurs when the reinforcing value of one component is reduced, so that the total amount of reinforcement is less. If R_1 is the response rate in the unaltered component

$$R_1 = \frac{kr_1}{\Sigma m_i r_i} \qquad (1)$$

where the m_i are multiplicative coefficients. The value $\Sigma m_i r_i$, the total reinforcement context is interpreted in the broad sense, so that a change in schedule which maintains the reinforcement rate can alter $\Sigma m_i r_i$. Relative preferences for different schedule types may be established by means of concurrent chains schedules (e.g. Fantino, 1968). Like other accounts of contrast this hypothesis needs to be more completely tested. However, it offers promise of quantification, thereby allowing precise testing.

We will now consider another set of contrast data which have presented difficulties for the theories described above, and have led to a further account. This "additivity theory" relies heavily on the results of studies of autoshaping which are reviewed in detail by Schwartz and Gamzu (1977). These authors also describe the evidence for and against the additivity theory in more detail than will be attempted here.

Additivity Theory

If we consider the standard procedure for demonstration of positive contrast, changing from multiple VI VI to multiple VI EXT, it can be seen that the VI component stimulus becomes a predictor of food (or whatever reinforcement) and the EXT component stimulus a predictor of its absence. Thus both response-reinforcer (operant) and stimulus-reinforcer (Pavlovian) contingencies are imposed by the multiple VI EXT schedule, while the multiple VI VI schedules impose only the former. If the behaviour engendered by the excitatory Pavlovian contingency is both directed at, and measured by, the manipulandum, more responses will occur in the unchanged component during multiple VI EXT than during multiple VI VI. These additional responses will thus be responsible for a positive contrast effect. This is the basis of additivity theory.

According to the theory, observations of contrast are to come extent fortuitous since the subjects are most frequently pigeons, the discriminative stimuli are usually located on the key, and the operant and reflexive responses (key-pecking) are recorded as being exactly the same. If either the stimuli are located away from the manipulandum or the behaviour engendered by the Pavlovian contingencies is not measured as operant, contrast will not occur.

Confirmation of the predictions of additivity theory is clearly demonstrated in Keller's (1974) study. The subjects were pigeons, the reinforcer food and the operant key-pecking. However, the discriminative stimuli were located on a second key, and pecks on this key were also measured. No responding occurred on the stimulus key during multiple VI VI, but pecking was maintained at a substantial rate on this key during the VI component of multiple VI EXT. Responding on the other key during the unchanged component did not alter significantly. Thus behavioural contrast could only be shown if both operant pecks (on the operant key) and reflexive pecks (on the stimulus key) were summed. With the usual arrangement of stimuli on the operant key this will occur automatically. This experiment and a large number of others employing pigeons key-pecking support the predictions of the additivity theory (see Schwartz and Gamzu, 1977, for a review).

Further support for this account comes from failures to obtain contrast. For example, neither Hemmes (1973) nor Westbrook (1973) obtained contrast effects with pigeons bar-pressing, as additivity theory would predict. Such evidence must be regarded as less reliable than positive demonstrations of the occurrence of reflexive behaviour, such as Keller's (1974). In this instance, some contradictory evidence is provided by McSweeney (1978) who obtained negative but not positive behavioural contrast in an experiment similar to Hemmes' and Westbrook's. Procedural differences suggest that contrast may not have been observed in the other experiments simply because of failure to obtain enough discrimination between the components.

Other recent evidence has suggested that contrast effects can be obtained in situations where additivity theory would not predict it. Bouzas and Baum (1976) defined a response of standing on a platform, and measured the time spent on this platform in each component. Diffuse overhead illumination signalled the components. Contrast was reliably obtained despite violation of the requirements suggested by additivity theory. Similarly, Gutman (1977) employed rats with a bar-pressing response. Contrast was obtained with either a doorlight or white noise as the discriminative stimulus.

Hearst and Gormley (1976) directly compared contrast effects obtained with on-key and off-key (houselight or clicker) stimuli. While the effects were more pronounced with the former, some contrast was obtained with off-key stimuli.

The evidence against the additivity theory is even stronger for negative contrast (e.g. Schwartz, 1975), and there are results which suggest that positive and negative contrast are independent phenemona (e.g. Bernheim and Williams, 1967). The conclusion of a number of authors has been that behavioural contrast is not a unitary phenomenon. While additivity theory correctly predicts the results of many experiments, the number of contrary instances suggests that it is only a partial explanation. Rather than discard additivity theory altogether it may be more fruitful to discover the conditions under which it is valid.

Schwartz, Hamilton and Silberberg (1975) showed that reflexive key-pecks mainly occur early in the VI component of multiple VI EXT (reflexive and operant pecks may be distinguished on the basis of their duration: Schwartz and Williams, 1972). From this they concluded that the Pavlovian contingencies may account only for local positive contrast. Supporting evidence comes from Spealman (1976) and Schwartz (1978). The latter author suggested that "local contrast effects, and that portion of overall contrast that can be attributed to local contrast, may be the proper province of additivity theory".

Positive contrast may be due to a local contrast effect, to an increase in response rate throughout the component or both. The Pavlovian contingencies may be assigned a role in producing this contrast according to the strength of the local contrast. Unfortunately, most experiments reporting overall contrast do not record data which describe local contrast effects so that the frequencies with which contrast occurs solely or partially because of a local contrast effect cannot be ascertained.

One other point should be made concerning the province of additivity theory. The results of an experiment by Woodruff, Conner, Gamzu and Williams (1977) suggest that behaviours resulting from stimulus-reinforcer and response-reinforcer contingencies may be mutually inhibitory. They manipulated the strength of each in multiple VI EXT schedules and found that the strength of one can be increased by lowering the strength of the other. Thus experimental procedures which favour the production of one type of contingency may expect to find little contrast due to the effects of the other. To some extent then, similar contrast effects may be obtained through the action of the different contingencies. The determining factor will be the particular experimental arrangement employed.

Overview

No single account of contrast has proved to be adequate. Each theory has been able to show sufficient conditions for contrast, but a synthesis which will allow a statement of the necessary conditions remains elusive. Clearly, both stimulus-reinforcer and response-reinforcer contingencies may play a part, although the experiment by Woodruff _et al_ (1977) suggested that if the role of one is important the other is likely to contribute little.

One important question to be answered is the role of local contrast effects in the production of contrast. More experiments which measure both types of response rate change are required to decide this issue. This has been attempted in the experiments to be described in this chapter. Using rats, results will first be obtained from procedures analogous to the standard methods for obtaining contrast with pigeons. We will then examine the dependence of both local and overall contrast effects on stimulus reinforcer contingencies. A final experiment will examine one type of control which should be used in assessing the role of stimulus-reinforcer contingencies.

To maintain comparability between experiments, many aspects of the method employed were kept constant. These will be described first.

5.3 GENERAL METHOD

Subjects

A total of 10 male Wistar hooded rats served as subjects in these experiments. Their ages at commencement of the experiment in which they served varied from 4 to 6 months. They were maintained on a 23-hour food deprivation cycle for one week prior to commencement, and during running were allowed free feeding for 1 hour after the end of each session. Access to water was free.

Housing was in individual cages in a temperature and humidity controlled room with a 12-hour day/12-hour night cycle.

Apparatus

One experimental chamber was used for all subjects in all experiments. It measured 22 cm x 22 cm x 21 cm high. A 5 cm bar protruded 2 cm into the chamber and could be operated by a downward force of 0.03N. The middle of the front of the bar consisted of a 4 cm wide x 1 cm high perspex section which could be illuminated by a 1W globe directly behind it. The bar was situated 9.5 cm above the floor in the middle of one panel.

A stainless steel chain 14 cm long could be hung from the ceiling, 10 cm away from the bar at the closest point. The chain consisted of 0.5 cm links and supported a 2.3 cm diameter ring. It could be operated by a downward force of 0.51N.

Directly below the bar was a food magazine into which could be deposited 45 mg Noyes pellets by a Gerbrands pellet dispenser. On the opposite wass was a single 3W globe which could be used to illuminate the chamber. A white noise generator which masked external sounds, and a buzzer were mounted on the plate supporting the chamber. This was all enclosed in a sound resistant shell with an exhaust fan in one wall. The ambient illumination, measured facing the rear of the chamber, was .028 foot-lamberts with bar-light only on, and 0.32 foot lamberts with only the houselight on.

Control of the experiment and recording of data were performed by a PDP-11 computer.

Procedure

Several aspects of the procedure were common to all experiments. Reinforcement consisted of delivery of a single pellet and was signalled by a 0.5 sec sounding of the buzzer. Sessions lasted 60 minutes, and were conducted 7 days a week.

All VI schedules had a mean interreinforcement interval of 1 minute and were composed of 10 intervals derived from

Catania and Reynolds' (1968) formula. For multiple VI VI the intervals were arranged in different orders for the 2 component schedules.

The discriminative stimulus used to signal the component of the multiple schedule in operation was the bar-light. For each pair of component schedules the first schedule operated while the bar-light was on and the second while it was off. The bar-light was always off when a single VI schedule was in operation. Multiple schedule components lasted 100 seconds and were strictly alternated. Which of the components was in operation at the beginning of each session was determined automatically according to a random process.

To obtain local response rates each of the components was divided into ten 10 second segments, and the number of responses in each segment recorded.

5.4 EXPERIMENT 1

The first experiment was designed to measure both local and overall contrast in an experimental situation analogous to that employed with pigeons. Reports of local contrast with rats are rare: Bernheim and Williams (1967) found evidence of local positive contrast in the behaviour of 2 of their 4 subjects, while all subjects showed local negative contrast, as did those of Williams (1965). Bernheim and Williams (1967) employed a somewhat atypical experimental procedure in that the reinforced response was wheel running. The effect of reinforcement contingencies on this response do not always match those obtained when the response is a discrete one such as bar pressing (e.g. Skinner and Morse, 1958).

Local contrast effects have been more reliably obtained when pigeons are used. This is consonant with additivity theory since the response reinforced is customarily key-pecking and the stimuli are located on the manipulandum. In this experiment the stimuli were placed on the bar. According to additivity theory, behaviour induced by the stimulus-reinforcer contingencies should be directed at the bar, and if it causes closure of the microswitch, positive local contrast should be observed. That this will occur is suggested by the fact that in an initial study bar-pressing was successfully autoshaped and maintained under an omission contingency (Williams and Williams, 1969) in the same apparatus to be employed in the series of experiments described here.

The contribution of local contrast to any overall contrast effects may be assessed in this experiment. Most authors have suggested that local contrast effects cannot fully account for overall contrast. For example, Nevin and Shettleworth (1966) reported persistent contrast, but only transient local contrast effects. As mentioned above, if additivity theory can accurately predict the occurrence of local positive contrast, the extent to which this is responsible for positive behavioural contrast determines the province of additivity theory in explaining overall contrast effects.

METHOD

Subjects

Two rats, R61 and R62 began the experiment, but R62 died during the course of running.

Procedure

Pretraining consisted of a session of continuous reinforcement followed by 6 sessions of exposure to a VI 1-minute schedule. The bar-light was off during this preliminary training. The reinforced response was bar-pressing and the houselight was on for the duration of all sessions.

R61 was exposed to multiple VI VI, multiple VI EXT, multiple VI VI, multiple EXT VI and multiple VI VI. The respective lengths of exposure were 19, 46, 18, 40 and 30 sessions. R62 was exposed to multiple VI VI for 43 sessions and multiple EXT VI for 38 sessions.

RESULTS

Figure 5.2 shows response rate in each component for each animal. This was averaged over blocks of 5 sessions, except for the last blocks of multiple VI EXT and the second exposure to multiple VI VI for R61, which represent averages over 6 and 3 sessions respectively. For each animal averages over the last two five-session blocks only are shown for the first exposure to multiple VI VI. Although in both cases response rate appears to have been increasing when the first schedule change was made, response rates as high as or higher than that in the last block had been attained during earlier periods of exposure to multiple VI VI.

The most striking aspect of these data is the absence of any large difference in response rate between EXT components and the VI components with which they were paired. No marked decrease in response rate was observed in components changed from VI to EXT. This failure to discriminate the two components is surprising considering the salience of the discriminative stimuli used to signal the components.

Neither contrast nor induction are evident in the data from R62. If only the first 25 sessions of R61's exposure to multiple VI EXT are considered there is clear evidence of

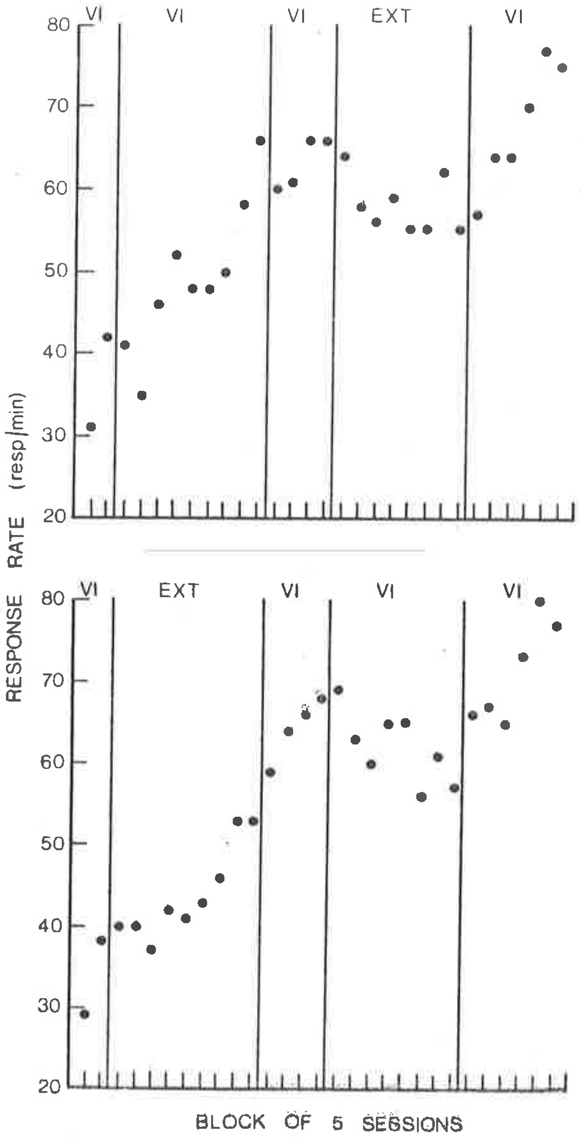

FIGURE 5.2: For R61, response rate in each component averaged over 5 session blocks (but see text for exceptions). The upper graph shows response rate in the component signalled by the bar-light being on, the lower response rate in the bar-light-off component. The schedules in operation in each component are indicated.

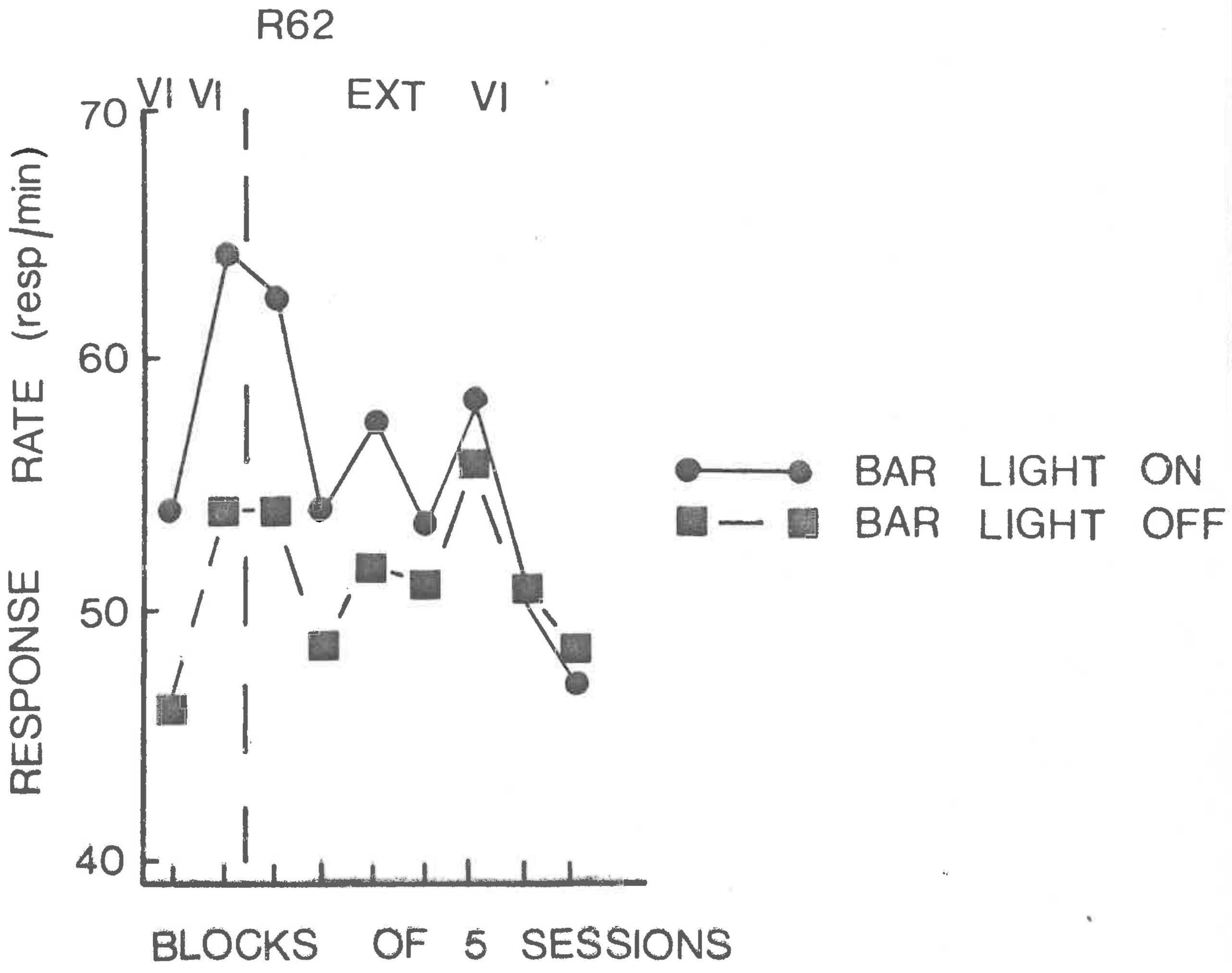

FIGURE 5.2: (contd) For R62 response rate in each component averaged over 5 session blocks. The schedules associated with each component are indicated.

positive behavioural contrast. Response rate was lower in the EXT component, while rate in the unchanged component increased from that in multiple VI VI. However, the picture is confused by the increase in rate in both components over the last 4 blocks. The reason for this is unclear.

The transition back to multiple VI VI yielded some evidence of negative contrast. Response rate in the bar-light on component dropped sharply, while response rate continued to rise in the bar-light off component. The results of the final two transitions, in which the bar-light off component was constan were negative and positive induction respectively. Changes in response rate in the bar-light on component were paralleled by changes in the bar-light off component.

Evidence for local contrast is presented in Figure 5.3. For each animal response rate in each of the 20 segments has been averaged over the last 5 sessions of each condition. In each case response rate showed no particular directional change as a function of elapsed time in the component when the schedule was multiple VI VI. However, strong local contrast effects were obtained when one of the components was EXT, most particularly in the data from R61. Response rate decreased through VI components (local positive contrast) and increased through EXT components (local negative contrast). The changes were erratic rather than smooth, but in each case there was a distinct trend.

In order to assess the development of local contrast effects with exposure to each schedule, average response rates in the first and second halves (the first and second groups of 5 segments) of each component were calculated from R61's data and are shown in Figure 5.4. Session blocks are the same as

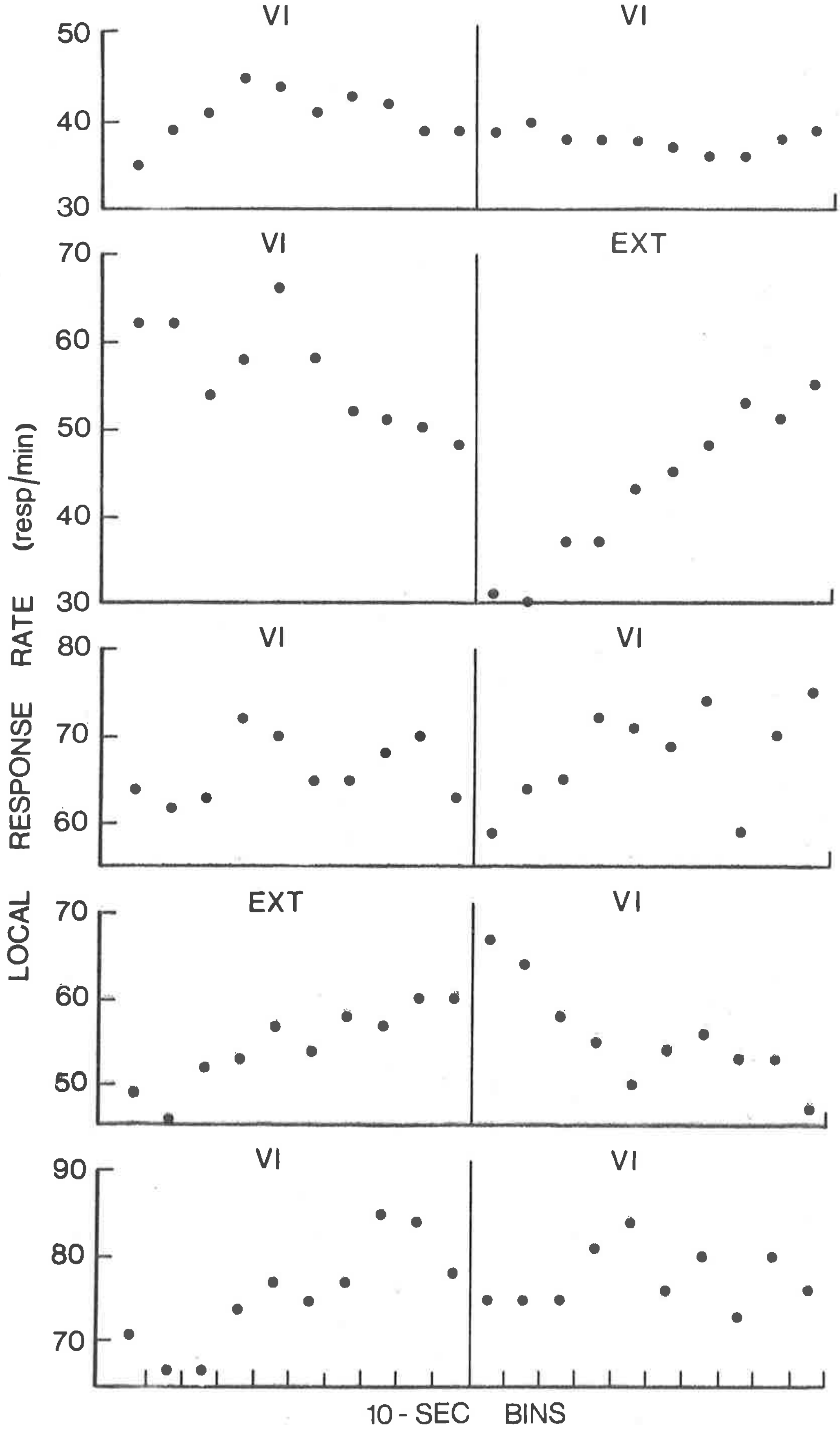

FIGURE 5.3: For R61 response rate in each of ten 10 sec segments dividing each component. The first half of each graph shows the local response rate pattern in the bar-light-on component, the second shows the pattern in the bar-light-off component. The schedules in operation in each component are indicated.

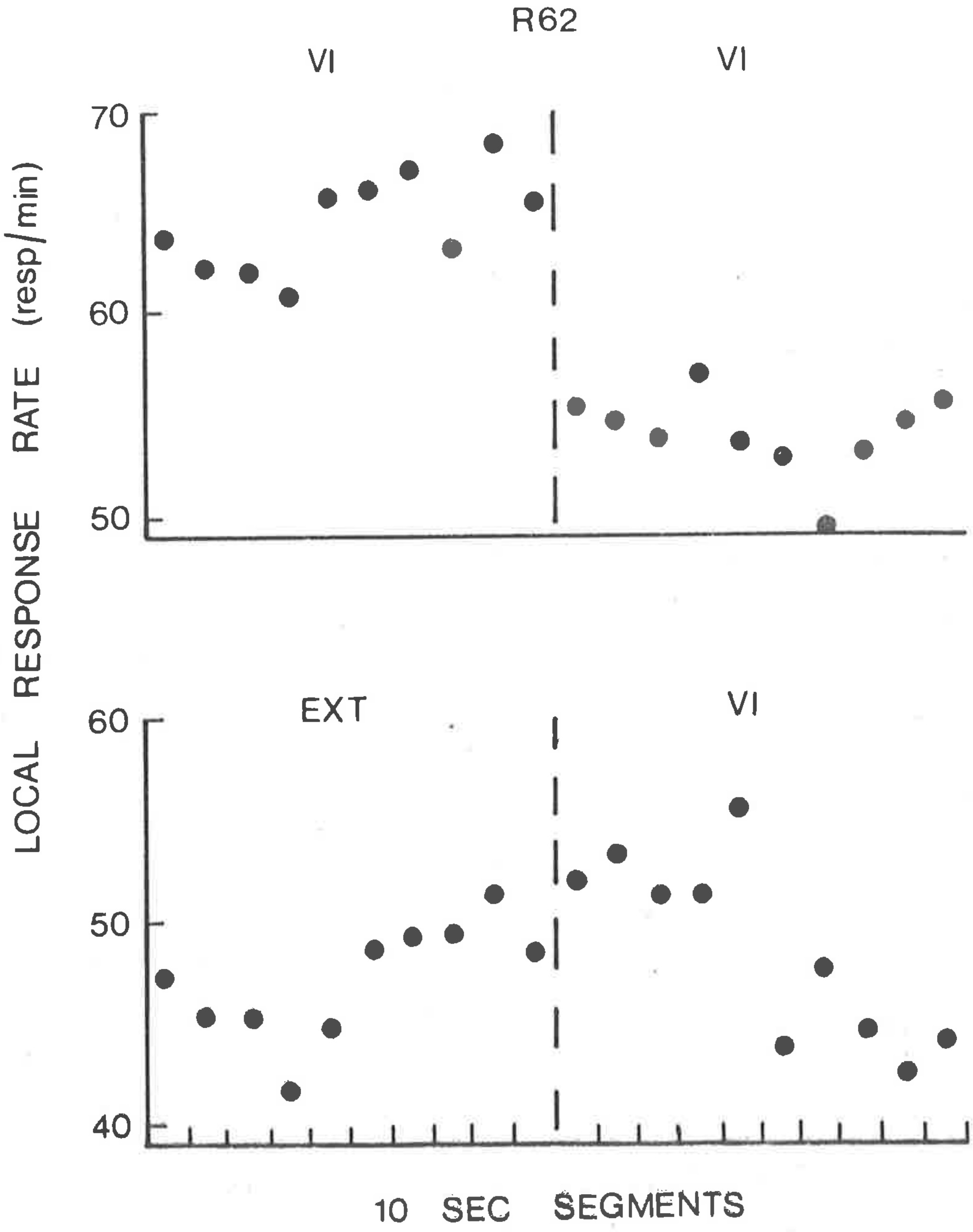

FIGURE 5.3: (contd) For R62 response rate in each of ten 10 sec segments dividing each component. The first half of each graph shows the local response rate pattern in the bar-light-on component, the second shows the pattern in the bar-light-off component. The schedules in operation in each component are indicated.

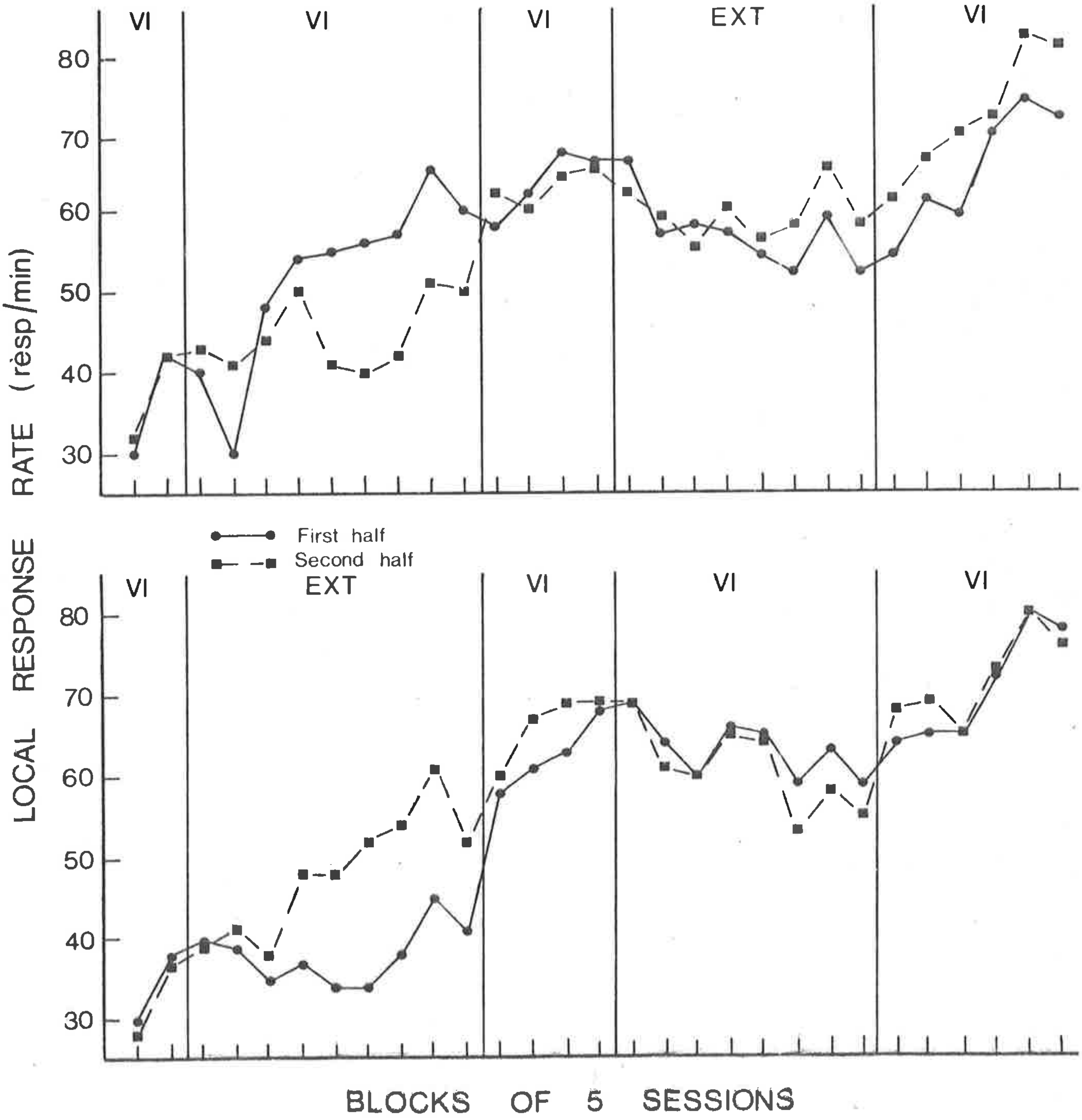

FIGURE 5.4: For R61 local response rate in the first and second halves of each component plotted over the same session blocks as Figure 5.2. The upper graph concerns the bar-light-on component and the lower the bar-light-off component. The schedules in operation are indicated.

in Figure 5.2. Local negative contrast appeared after 10 sessions of exposure to multiple VI EXT and local positive contrast after 20. After these points response rate in the first half of the VI component and the second half of the EXT component rose with continued exposure. Response rates remained relatively constant in the other two halves, suddenly increasing when multiple VI VI was instituted. Throughout exposure to multiple EXT VI response rate remained relatively constant in the second half of the EXT and the first half of the VI components. In the other halves there was a gradual decline.

DISCUSSION

That local positive contrast can occur independently of positive behavioural contrast has been conclusively demonstrated here. Indeed local positive contrast may be associated with induction rather than contrast. We may therefore discuss two types of stimulus control which are imposed by a multiple schedule: the control exerted by the stimuli themselves and that exerted by the discriminative stimulus changes. Differences in overall response rate are primarily controlled by the former and local rate variation is primarily controlled by the latter.

Two aspects of the result suggests that control by the discriminative stimuli was relatively weak in this experiment. Most obviously, in each case the introduction of EXT failed to reduce response rate in that component to any considerable extent. This was despite up to 46 sessions of exposure to multiple schedules with EXT components. Secondly, evidence for induction was stronger than that for contrast, suggesting that the components may not have been adequately discriminated.

However, the control exerted by the changes from bar-light on to bar-light off and vice versa, as reflected in the strength of local contrast effects, seemed relatively strong. This follows if we regard local contrast effects as gradients of response rate determined by temporal location with respect to these changes. Figure 5.4 showed that sharpness of the gradients tended to rise to an asymptote with increased exposure to the multiple schedule.

While both local positive and local negative contrast were obtained, it is not clear whether they reflect the action of both excitatory control (by the change from a stimulus signalling EXT to one signalling VI), inhibitory control (by the VI to EXT change), or both. Although the focus of additivity theory has been on excitatory stimulus-reinforcer contingencies, Schwartz and Gamzu (1977) noted that many of the results explained by the action of excitatory contingencies could equally well be explained by the action of inhibitory ones. The evidence from Figure 5.3 is somewhat contradictory. Excitatory effects seem most important in multiple VI EXT, while within-component rate differences appear to be due mainly to inhibitory influences in multiple EXT VI. The confounding of these two in the usual multiple schedule arrangement makes them relatively difficult to separate.

5.5 EXPERIMENT 2

The results of the first experiment suggested that the discriminative stimuli themselves exerted little control over the behaviour, while response rate gradients about stimulus changes were pronounced. In this experiment an attempt was made to increase the discriminative stimulus control by increasing the salience of the stimuli. The houselight was simply removed from the chamber so that the bar-light was the only source of illumination. By this means the state of the bar-light should be more dominant relative to time since the last stimulus change and until the next one. Greater changes in overall response rate should be observed under these conditions than were found in Experiment 1.

METHOD

Subjects

Two rats, R63 and R64.

Procedure

Preliminary training for both animals consisted of 3 sessions of continuous reinforcement followed by 20 sessions on a VI 1-minute schedule. For R63 the experiment proper consisted of exposure to multiple VI VI (21 sessions), multiple EXT VI (15 sessions) and multiple VI VI (9 sessions). For R64 it was multiple VI VI (10 sessions), multiple VI EXT (15 sessions) and multiple VI VI (12 sessions).

The only other variation from the procedure of the first experiment was the absence of the houselight throughout running.

RESULTS

Adjustment to each new schedule occurred relatively rapidly in this experiment. In particular, response rate quickly dropped to a low level when components changed from VI to EXT. Fewer sessions of exposure to each schedule were thus required in this experiment than the first. In addition, since neither animal died during running and there was no evidence of practice effects as was the case in the first experiment, each animal was exposed to only one multiple schedule with an EXT component.

For each animal response rate in each component is shown in Figure 5.5 as a function of length of exposure to each schedule in blocks of 3 sessions. The last 2 blocks only are shown for the first exposure to multiple VI VI. There is some evidence of contrast in these data. For R63 response rate in the unchanged component increased over the period when the other component was EXT and decreased again when the other component was returned to VI. The evidence for positive and negative behavioural contrast is clearer in these results than in those from R64. For this animal response rate in the unchanged component gradually increased during exposure to multiple VI EXT, but to a level only slightly above that attained in multiple VI VI. Reintroduction of the VI schedule in the other component had no effect initially, response rate then decreased, and finally increased to a value close to the highest level attained in multiple VI EXT.

Local response rates in each component, averaged over the last 5 sessions of each condition, are plotted in Figure 5.6. An excitatory effect resulting from stimulus change, particularly when the bar-light came on, was apparent in both exposures of R63 to the multiple VI VI schedule. This response pattern was persistent in showing no signs of diminishing with increased exposure to the schedule, and its origin is unclear. Nevertheless, strong local positive and local negative contrast were obtained. The results from R64 show only local positive contrast although the gradient was very pronounced.

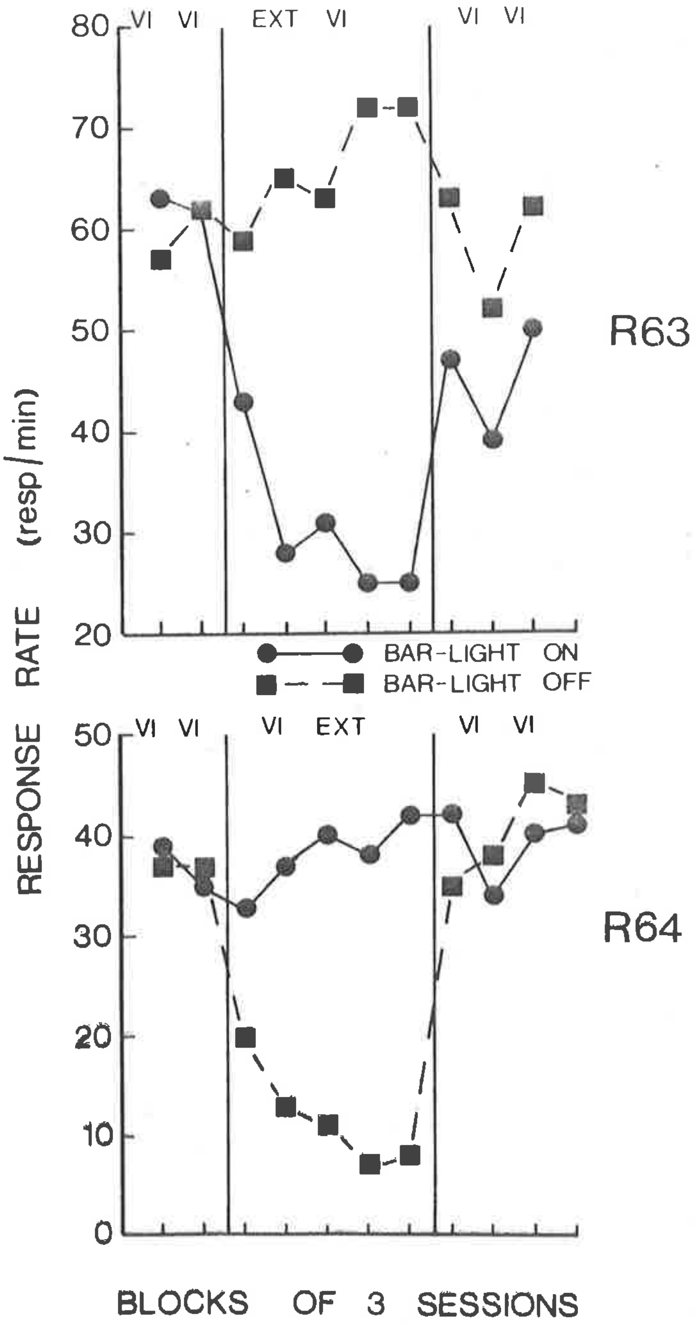

FIGURE 5.5: Response rate in each component averaged over 3 session blocks. The multiple schedule in operation is indicated.

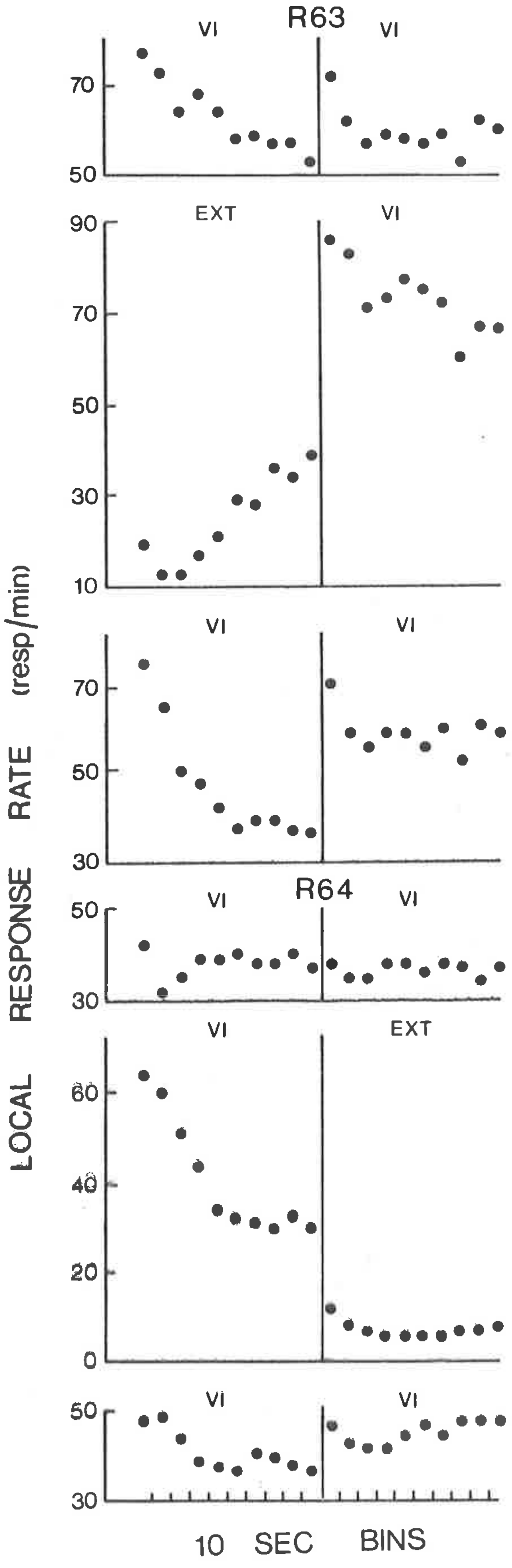

FIGURE 5.6: Response rate in each of ten 10-sec bins dividing each component. For each animal, the first half of each graph shows the pattern of local response rate changes in the bar-light-on component, the second shows the pattern in the bar-light-off component. The schedules in operation in each component are indicated.

DISCUSSION

The principal effect of increasing the salience of the discriminative stimuli was the lowering of response rate in EXT. The components were clearly discriminated in that the difference in response rates more closely resembled that obtained with VI and EXT schedules in isolation. Behavioural contrast, of which there was little evidence in the first experiment, was also obtained under the higher salience conditions of this experiment.

Similar results were obtained by Pear and Wilkie (1970). They employed mixed schedules (i.e. there were no discriminative stimuli signalling components). When the VI schedule yielded a high reinforcement rate it was discriminated from EXT and contrast was found. If the VI schedule had a high inter-reinforcement interval discrimination was poor and there was some evidence of induction. In a later experiment (Pear and Wilkie, 1971) they suggested that discriminability of the components should also affect negative contrast. Positive induction is more likely than negative contrast if the components are not well discriminated. In Experiment 1 positive induction was obtained in the third exposure of R61 to multiple VI VI.

The results also concur with Baum's (1974a) analysis of undermatching. He suggested that the degree of undermatching is increased by manipulations which decrease the discriminability of the component schedules. For example, the parameter _a_ of Equation 2.3 typically increases as component duration decreases in multiple schedules (see Section 2.10). A smaller value of _a_ would also mean a smaller contrast effect: the organism is less sensitive to the difference in reinforcement rates provided by the two components. In terms of Herrnstein's equation for multiple schedules (Equation 2.31) the value of m is smaller when the components are discriminated to a lesser extent. In Experiment 1 the value of m would have been close to 0.0 since failure to discriminate the components was almost complete.

Local contrast effects were little altered by increasing the salience of the discriminative stimuli. In both experiments local positive contrast was obtained for each subject, while local negative contrast failed to occur only in the case of R64. Thus it appears that under conditions analogous to those employed with pigeons, local contrast of rats' bar-pressing can be reliably obtained. In particular, local positive contrast would have been predicted by the additivity theory since bar-pressing can be autoshaped with the bar-light as stimulus (see above).

The local contrast effects observed in this and the first experiment showed no signs of diminishing as length of exposure to the schedule increased. Some studies (e.g. Boneau and Axelrod, 1962, and Nevin and Shettleworth, 1966) have indicated that transience may be a property of local contrast. Malone and Staddon (1973) suggested that the number of different stimuli employed and their discriminability may differentiate studies which have found persistence (as they did) from those which found transience. If only a few relatively easily discriminated stimuli are used, local contrast may tend to disappear after extended exposure. However, this experiment satisfied both criteria and yet there was no evidence of weakening of local contrast. Also, if average maintained response rates are an indicator, the stimuli were discriminated much better in this experiment than the first, yet the only noticeable difference between the two was the more rapid appearance of local contrast effects in this experiment. Malone and Staddon's (1973) account of local contrast effects in terms of inhibitory and excitatory effects generated by stimuli of different relative values is also difficult to apply to the first experiment. Overall response rates would indicate little difference in value of the two components, but strong and persistent local contrast effects were obtained. It thus appears that a lower reinforcement rate in one component, although producing little difference in overall response rates, is sufficient for the production of local contrast.

5.6 EXPERIMENT 3

With sufficient conditions for both overall and local contrast established in the first two experiments, an analysis may be made of the contribution of the stimulus-reinforcer and response-reinforcer contingencies maintaining these effects. The method of topographical tagging (Catania, 1969) has been employed with pigeons to separate these two. In such experiments, mentioned above, the discriminative stimuli are located on a second key, so that operant and reflexive pecks may be measured independently.

However, this method fails to completely differentiate the roles of the two contingencies. Since the behaviour measured by the signal key falls in the same class as those responses reinforced on the operant key, the response-reinforcer contingency may be responsible for the topography of the behaviour directed at the signal key. In order to remove any effect of the response-reinforcement contingency in guiding the topography of the elicited behaviour, the discriminative stimuli should be located on a separate manipulandum which records responses different from those reinforced according to the VI schedules. In this experiment the stimuli were on the bar, as before, but the reinforced response was chain-pulling. The topography required for an elicited response to be measured thus differed substantially from that required by the reinforcement contingencies.

If the response-reinforcer contingencies are sufficient to completely account for overall and local contrast effects the results obtained in the first two experiments should be largely replicated in the chain-pull data here. If they play some role in guiding the topography of elicited responses small contrast effects may be seen in the bar-pressing data. However, if, as a strong version of additivity theory would predict, they play no role, full flown overall and local contrast effects should be observed in the bar-pressing data. The experiments were arranged as before: firstly with the houselight and secondly with no houselight.

METHOD

Subjects

Two rats, R71 and R72.

Procedure

Preliminary training consisted of hand-shaping of the chain-pull response followed by 10 sessions of exposure to a VI 1-minute schedule. For R71 the experiment proper composed exposure to multiple VI VI (17 sessions), multiple EXT VI (50 sessions), and multiple VI VI (10 sessions). For R72 it was multiple VI VI (14 sessions), multiple VI EXT (50 sessions), and multiple VI VI (15 sessions).

The houselight was on for the duration of each session.

RESULTS AND DISCUSSION

As was the case in the first experiment, changing one component from VI to EXT had little effect on the rate of responding maintained during that component (Figure 5.7). Chain-pull rate in the unaltered component was not affected by this shift either. There was some evidence of induction-like effects in the chain-pull data: when the component was changed from EXT to VI both response rates increased. Since there was no difference in the rates during multiple EXT VI this cannot be termed induction according to the definitions above.

The bar-press data similarly failed to show any induction or contrast effects. R71 maintained a higher bar-press rate when the bar-light was on from the beginning of exposure to the multiple schedules, but this was unaffected by the changes from VI to EXT and EXT to VI. Again it appears that a relatively salient stimulus was not sufficient for adequate discrimination between the schedules, even though exposure to the multiple schedules with EXT components was continued for 50 sessions to give sufficient opportunity for discrimination.

Unlike the results of Experiment 1, however, there was little evidence of local contrast effects here. Figure 5.8 shows the pattern of chain-pulling within each of the components. There was no particular tendency to an increasing or decreasing rate when multiple VI VI was in operation. The results from R72 with multiple VI EXT showed some evidence of local positive contrast. Response rate decreased through the

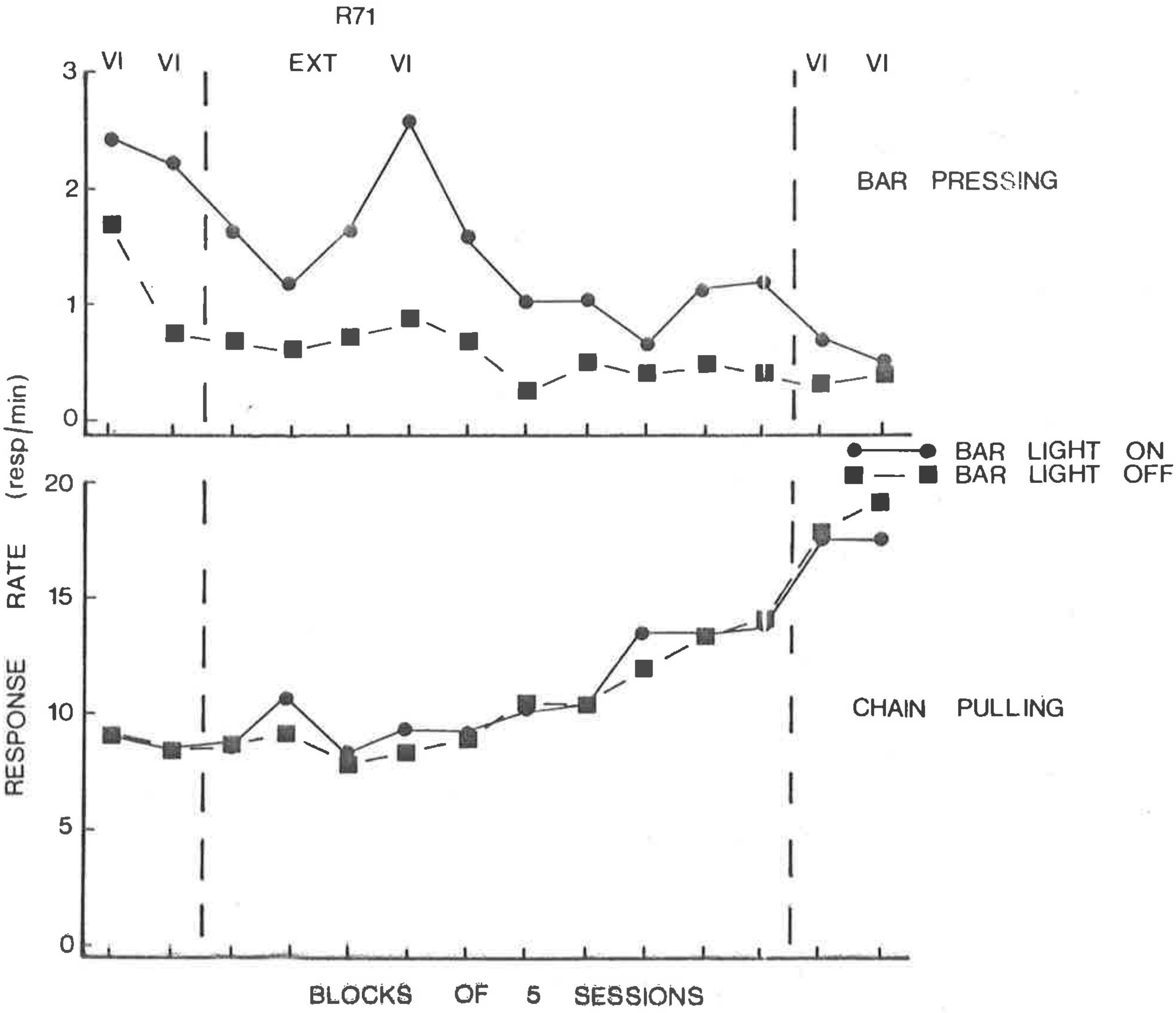

FIGURE 5.7: For R71, bar-pressing rate and chain-pulling rate in each component averaged over 5 session blocks. The multiple schedule in operation is indicated.

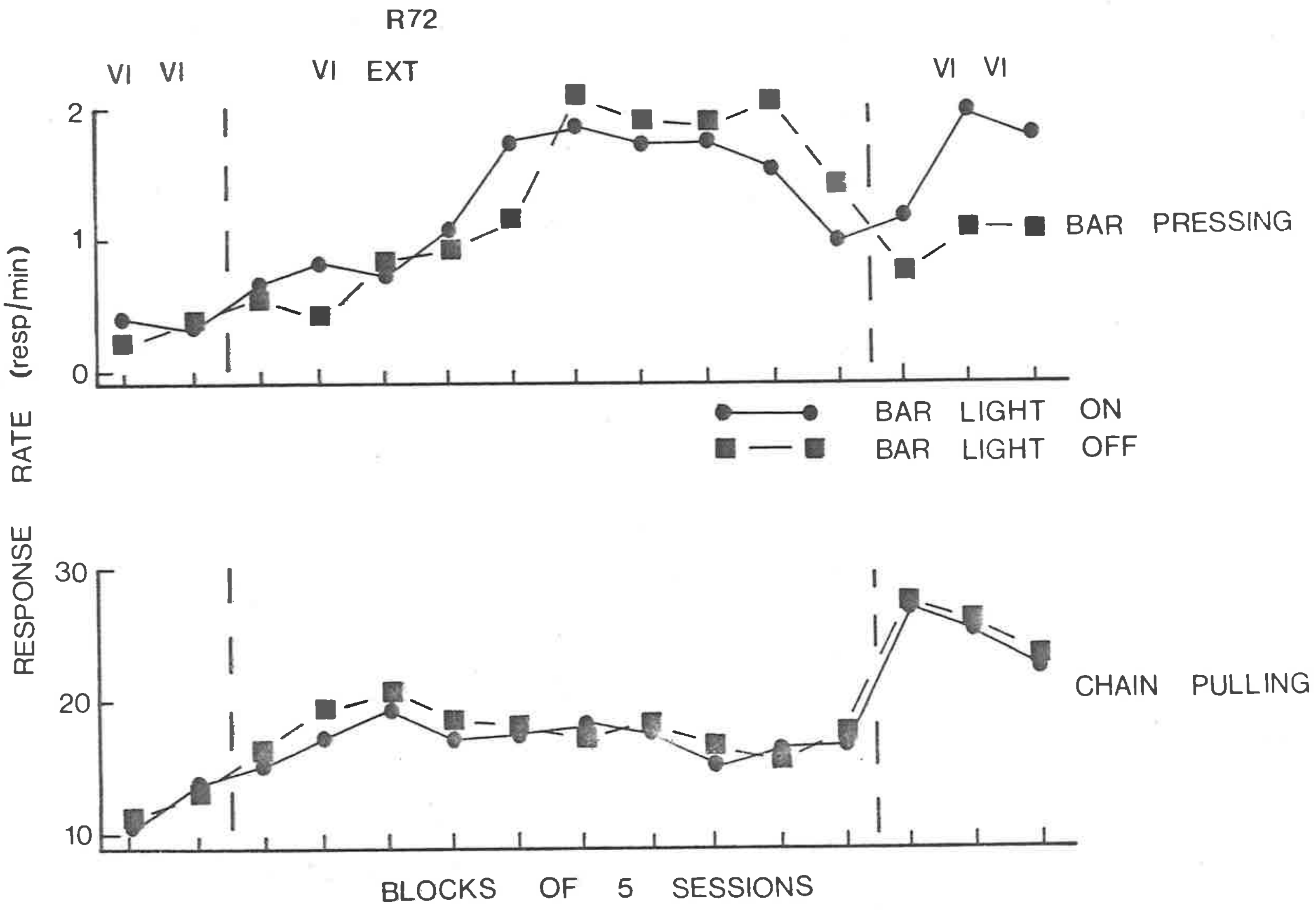

FIGURE 5.7: For R72, bar-pressing rate and chain-pulling rate in each component averaged over
(contd) 5 session blocks. The multiple schedule in operation is indicated.

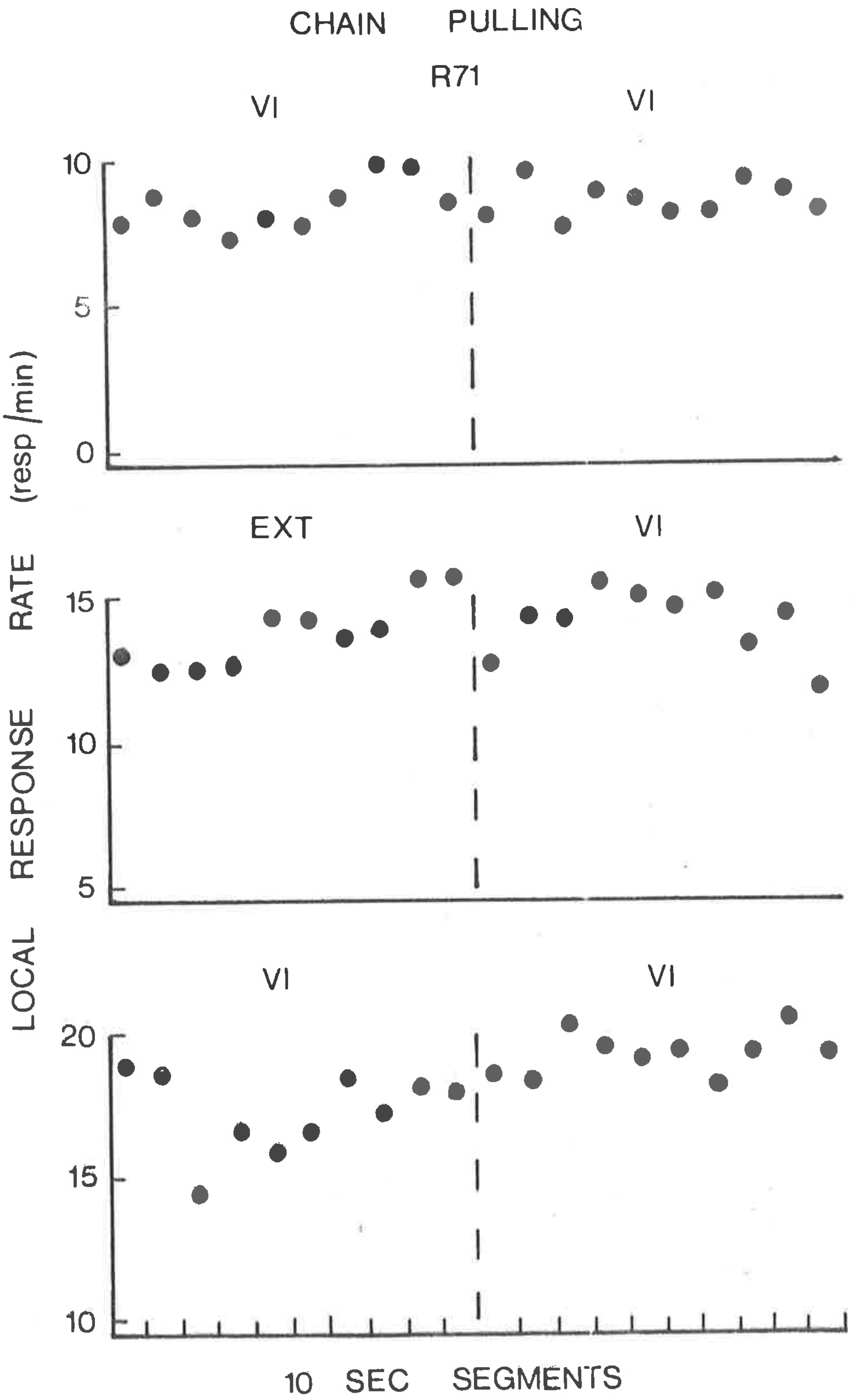

FIGURE 5.8: For R71, chain-pulling rate in each of the ten 10-sec segments dividing each component. The first half of each graph shows the local response rate pattern in the bar-light-on component, the second shows the pattern in the bar-light-off component. The schedules in operation in each component are indicated.

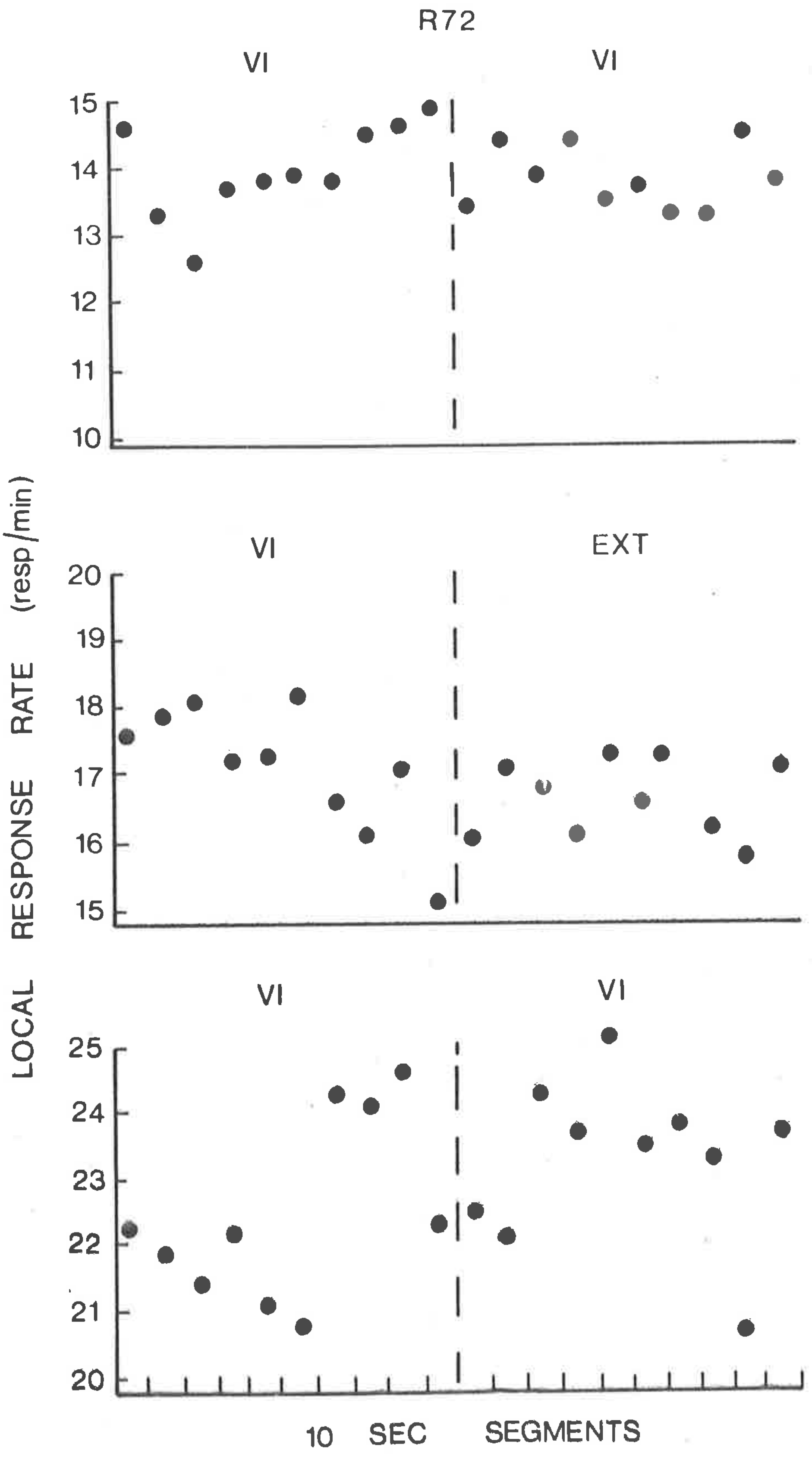

FIGURE 5.8: (contd) For R72, chain-pulling rate in each of the ten 10-sec segments dividing each component. The first half of each graph shows the local response rate pattern in the bar-light-on component, the second shows the pattern in the bar-light-off component. The schedules in operation in each component are indicated.

VI component from about 18 to 15 responses per minute. Responding in the corresponding EXT component did not reveal any gradient however. Again with only a small range, R71 showed evidence of local negative contrast in the EXT component.

Local bar-pressing rate patterns (Figure 5.9) are more difficult to interpret. The baseline pattern during R71's first exposure to multiple VI VI was not stable, but decreased during the bar-light off component. The only trend in multiple EXT VI was to a decreasing rate during the EXT component. According to the definitions, since the VI component was maintaining the lower bar-press rate, this should be termed local positive contrast. For R72 the tendency was to an increase in response rate through the EXT component local negative induction. Neither of these observations should be given much weight, however, since bar-press rates were low and extremely variable.

5.7 EXPERIMENT 4

Because of the complete failure of the subjects in Experiment 3 to discriminate the components an alternative procedure was employed in this experiment. In addition to the bar-light being the only source of illumination in the chamber, simple VI schedules were employed in place of multiple VI VI schedules. Thus the 3 schedules to which each subject was exposed were VI, multiple EXT VI and VI. Using this procedure the appearance of the bar-light is correlated with the introduction of parts of each session in which no reinforcers are delivered.

This method has been employed in a number of other experiments (e.g. Pear and Wilkie, 1971), with results that

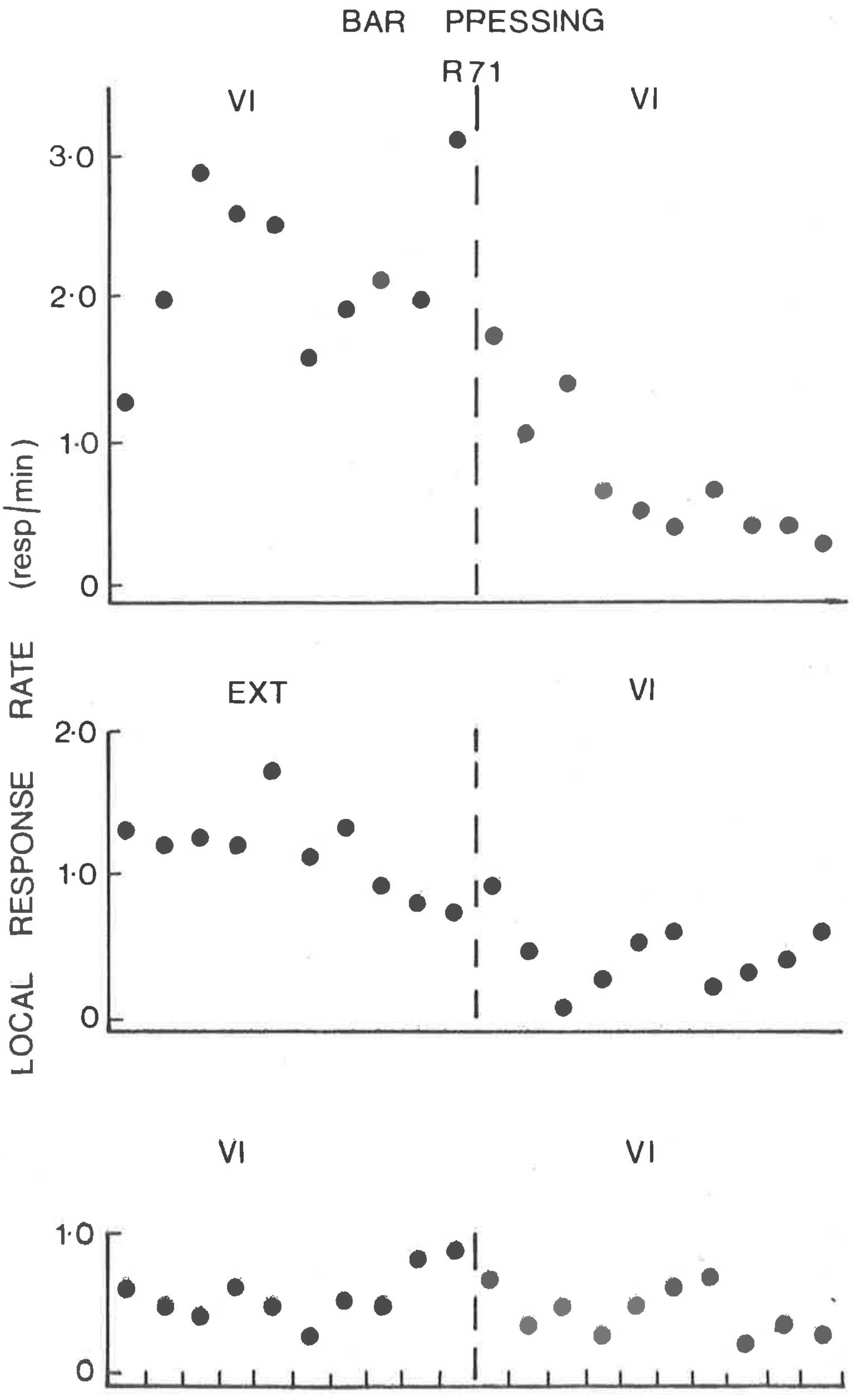

FIGURE 5.9: For R71, bar-pressing rate in each of the ten 10-sec segments dividing each component. The first half of each graph shows the local response rate pattern in the bar-light-on component, the second shows the pattern in the bar-light-off component. The schedules in operation in each component are indicated.

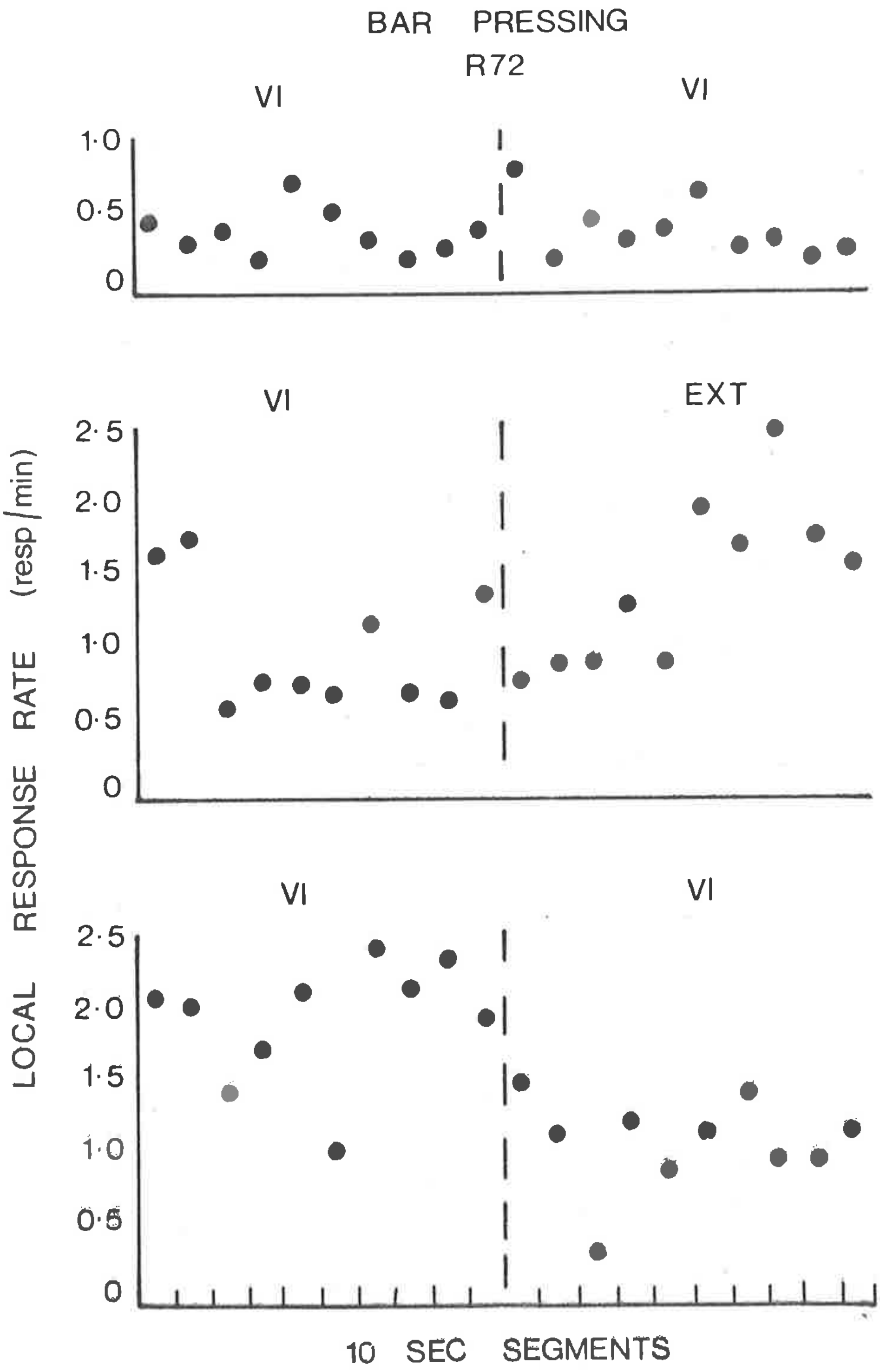

FIGURE 5.9: (contd) For R72, bar-pressing rate in each of the ten 10-sec segments dividing each component. The first half of each graph shows the local response rate pattern in the bar-light-on component, the second shows the pattern in the bar-light-off component. The schedules in operation in each component are indicated.

do not appear to differ significantly from those obtained with usual procedures. Since the stimulus signalling EXT will not have been associated with a VI schedule previously, discrimination of the VI and EXT components should be more rapid. No reinforcers will have been obtained in the presence of the stimulus associated with the EXT component.

As Gamzu and Schwartz (1977) have noted, the multiple VI VI schedule is analogous to the truly random control for Pavlovian conditioning described by Rescorla (1967). Any differential effects noted when multiple EXT VI is in operation must be evaluated against the results from this stage. From earlier experiments it can be seen that there is an occasional tendency for a higher response rate in the bar-light on component when both stimuli signal VI schedules, and a tendency to a high local response rate soon after the onset of the light. Since the bar-light will be associated with EXT in this experiment such tendencies will oppose the likely effects of introducing EXT: response rate will be lower in this component and the probable pattern of responding is an increase through the component. Thus the results obtained are not likely to be due to the introduction of the bar-light per se, but the correlation of this stimulus with EXT.

METHOD

Subjects

Two rats, R73 and R74.

Procedure

Following hand-shaping of the chain-pull response the subjects were exposed to VI 1-minute schedules. This was for a period of 12 sessions in the case of R73 and 22 sessions for R74. Both were then exposed to multiple EXT VI: 24 sessions for R73 and 23 for R74. Re-exposure to the VI schedule lasted 13 sessions (R73) and 14 sessions (R74).

There was no houselight in operation throughout the period of the experiment, except when the response was being shaped. The EXT component was signalled by the bar-light being on.

RESULTS

Figure 5.10 shows the rates of both bar-pressing and chain-pulling in each component. These were averaged over blocks of 3 sessions, except for the last block of exposure to multiple EXT VI for R74 (average over 2 sessions), and the last block of the second exposure to VI for R73 (4 session average) and R74 (2 session average). Only the final 2 blocks are shown for the first exposure to VI.

Discrimination between the schedules appeared from the first block. Response rate was extremely low in the EXT component and changed little with continued exposure to multiple EXT VI. The technique of introducing the bar-light together with the EXT component produced discrimination more rapidly than was achieved in the previous experiments.

Contrast effects were evident in the chain-pull data from R73 and R74. The pattern of results differs between the two, however. For R73 the initial effect of the introduction of the EXT component was a drop in the rate maintained by the VI schedule. Response rate then rose as exposure time lengthened revealing both positive and negative behavioural contrast. The results from R74 showed only transient positive behavioural contrast with little evidence of negative contrast.

One surprising result was that bar-pressing occured at a much higher rate during the EXT than the VI component for both

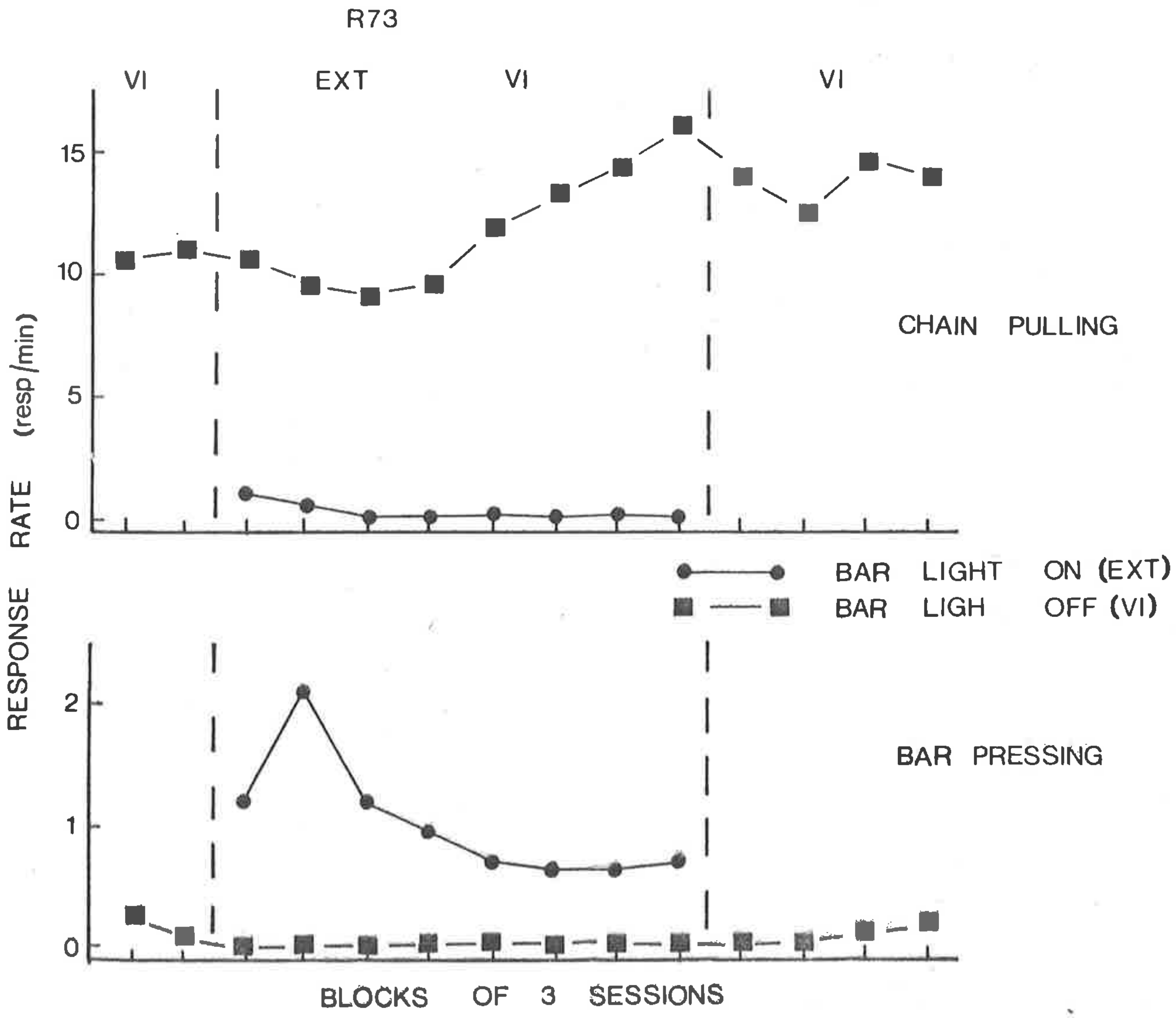

FIGURE 5.10: For R73, chain-pulling rate and bar-pressing rate in each component averaged over 3 session blocks. The schedule in operation is indicated.

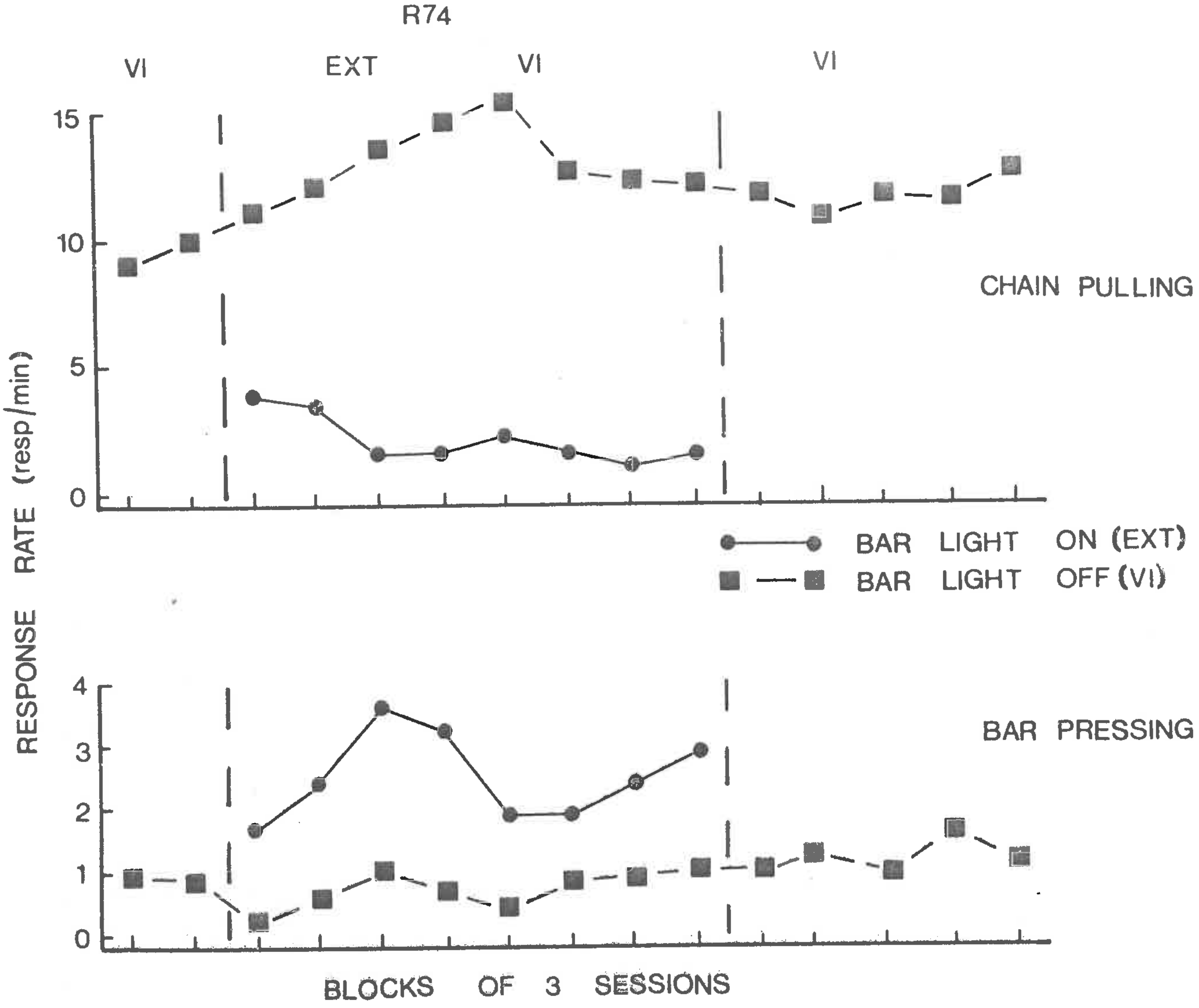

FIGURE 5.10: (contd) For R74, chain-pulling rate and bar-pressing rate in each component averaged over 3 session blocks. The schedule in operation is indicated.

animals. In addition the rate of bar-pressing during VI appeared to be lower during multiple EXT VI than VI. In both cases the rate during the EXT component was much higher than that maintained by VI alone. These results are in clear contradiction to the predictions of additivity theory.

Local rates of chain-pulling and bar-pressing in each component are shown in Figure 5.11. Chain-pulling rate was constant through EXT components for both animals. Similarly, there was no particular directional change through the duration of the VI component for R73. In the case of R74, however, local positive contrast was evident. The rate of chain-pulling decreased from the beginning to the end of the VI component. Again, such a result is in contradiction to additivity theory.

The patterns in the bar-pressing rates are not so clear. For R73 the rate at the beginning of the VI component was higher than at the middle and end, where it was zero. However, even the initial elevated rate was only 0.13 responses per minute. The rate of bar-pressing was much higher during the VI component for R74 and a clear decrease in rate through the component was evident, with the notable exception of the rate in the first 10 seconds. The reason for this exception is unclear. For both animals bar-pressing rate tended to increase through the EXT component but variation from this trend was high, particularly in the case of R74. Such variability is due in part to the relatively few responses used to calculate the rate in each segment.

DISCUSSION

The contrast effects observed with chain-pulling are consistent with other experiments which have demonstrated contrast

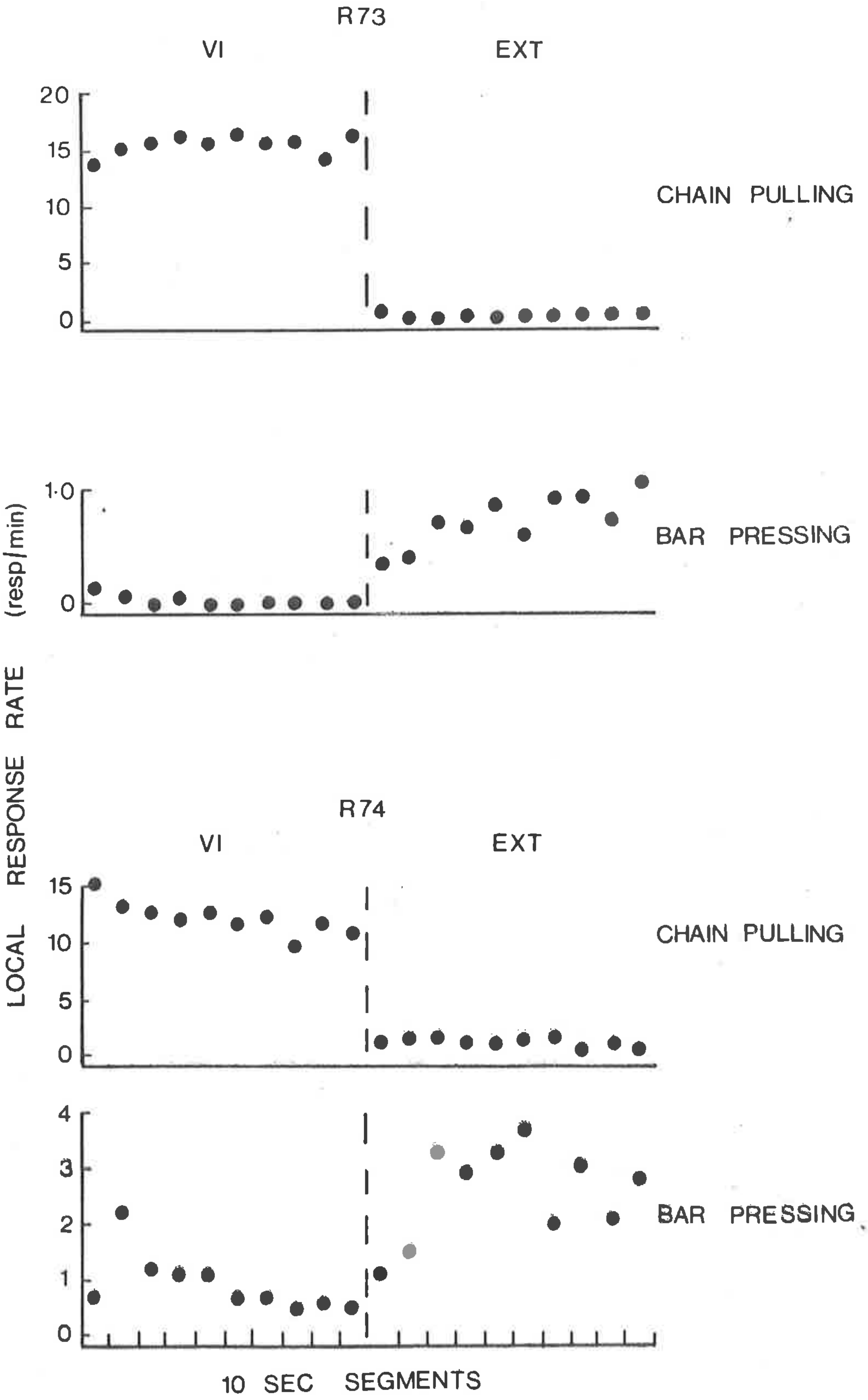

FIGURE 5.11: Chain-pulling rate and bar-pressing rate in each of the ten 10-sec segments dividing each component of the multiple EXT VI schedule. The first half of each graph shows the local response rate pattern in the VI component, the second shows the pattern in the EXT component.

when the discriminative stimuli were located away from the manipulandum. Beninger and Kendall (1975) and Gutman, Sutterer and Brush (1975) used rats as subjects while Hemmes (1973) and Hamilton and Silberberg (1978) employed pigeons. There is thus a considerable body of data which contradicts additivity theory's prediction that contrast will not occur under such conditions.

Even if this theory is restricted to an explanation of local positive contrast some results from these experiments are contradictory: local positive contrast was observed in the chain-pulling of subject R74 and in the previous experiment one subject (R72) showed a similar effect. Although it is not a reliable phenomenon, local positive contrast can occur when the stimuli are located off the manipulandum. Additivity theory therefore fails to predict the necessary conditions for local positive contrast.

Response rate gradients of bar-pressing within each component revealed local contrast effects. Bar-pressing tended to decrease through VI components and increase through EXT components. The gradients within VI components are consistent with additivity theory, but it makes no predictions about local negative contrast.

Although patterns of bar-pressing within components were consistent with additivity theory, overall rates are more difficult to explain. In particular, bar-pressing rate was much higher in EXT than VI components, and rate during VI tended to decrease when the EXT component was added. Bar-presses during EXT cannot be said to be due to stimulus-reinforcer contingencies since the light was a predictor of the absence of reinforcement. Similarly, bar-pressing was never reinforced according to the contingencies of the experiment. While there was a basic operant level of bar-pressing, exemplified by the rate when the simple VI was in operation, it is not clear why the rate should be greater in the absence of a chain-pull reinforcement contingency. One possibility is that with response competition from chain-pulling removed, the factors which produced the bar-pressing were able to maintain a higher rate of that response. If this is the case then the rates and patterns of bar-pressing observed may not have been dependent upon the discriminative stimuli being located on the bar. Any response which can be measured (e.g. by means of a manipulandum) may show the same patterning as the bar-pressing here.

5.8 EXPERIMENT 5

In this experiment bar-pressing was reinforced according to VI and multiple VI EXT schedules and measures were taken which would allow observation of both local and overall contrast effects. The conditions found to be optimal for discrimination between VI and EXT components were employed: the bar-light was the only source of illumination and it was introduced with the EXT component. The results should therefore be similar to those obtained in Experiment 2. In addition, the chain was placed in the chamber, although responses on this manipulandum had no effect. Measures of this response allowed observation of any changes in overall rate with changes in the bar-pressing contingencies, and any gradients of chain-pull rate within the multiple schedule components.

This experiment may be regarded as a control to assess the results of the previous two experiments. Stimulus reinforcer contingencies cannot be assigned responsibility for responding on a manipulandum which is located away from the discriminative stimuli. Any responding on the chain in this experiment cannot be due directly to the reinforcement delivered according to the schedules or to the signalling properties of the stimuli, but would be caused by other factors. The extent to which chain-pulling in this experiment differs from bar-pressing in Experiments 3 and 4 in both overall pattern and temporal properties will indicate the relative roles of stimulus reinforcer contingencies and the other factors in producing the bar-pressing observed in these experiments.

METHOD

Subjects

Two rats, R7B1 and R7B2.

Procedure

Bar-pressing was reinforced according to a continuous reinforcement schedule for 3 sessions. Each animal was then exposed to a VI schedule (23 sessions for R7B1 and 26 sessions for R7B2), multiple EXT VI (24 and 20 sessions), and VI (21 and 10 sessions).

The houselight was never on and the EXT component was signalled by the bar-light being on. The chain was in the chamber throughout the experiment but chain-pulling had no programmed consequences.

RESULTS

Figure 5.12 shows the rates of both bar-pressing and chain-pulling in each component. These are averages over blocks of 3 sessions, except for the final blocks of R7B2's exposure to multiple EXT VI and VI which are averages over 2 and 4 sessions respectively. Only the final 2 blocks are shown for the first exposure to VI. As was the case in Experiment 4, discrimination

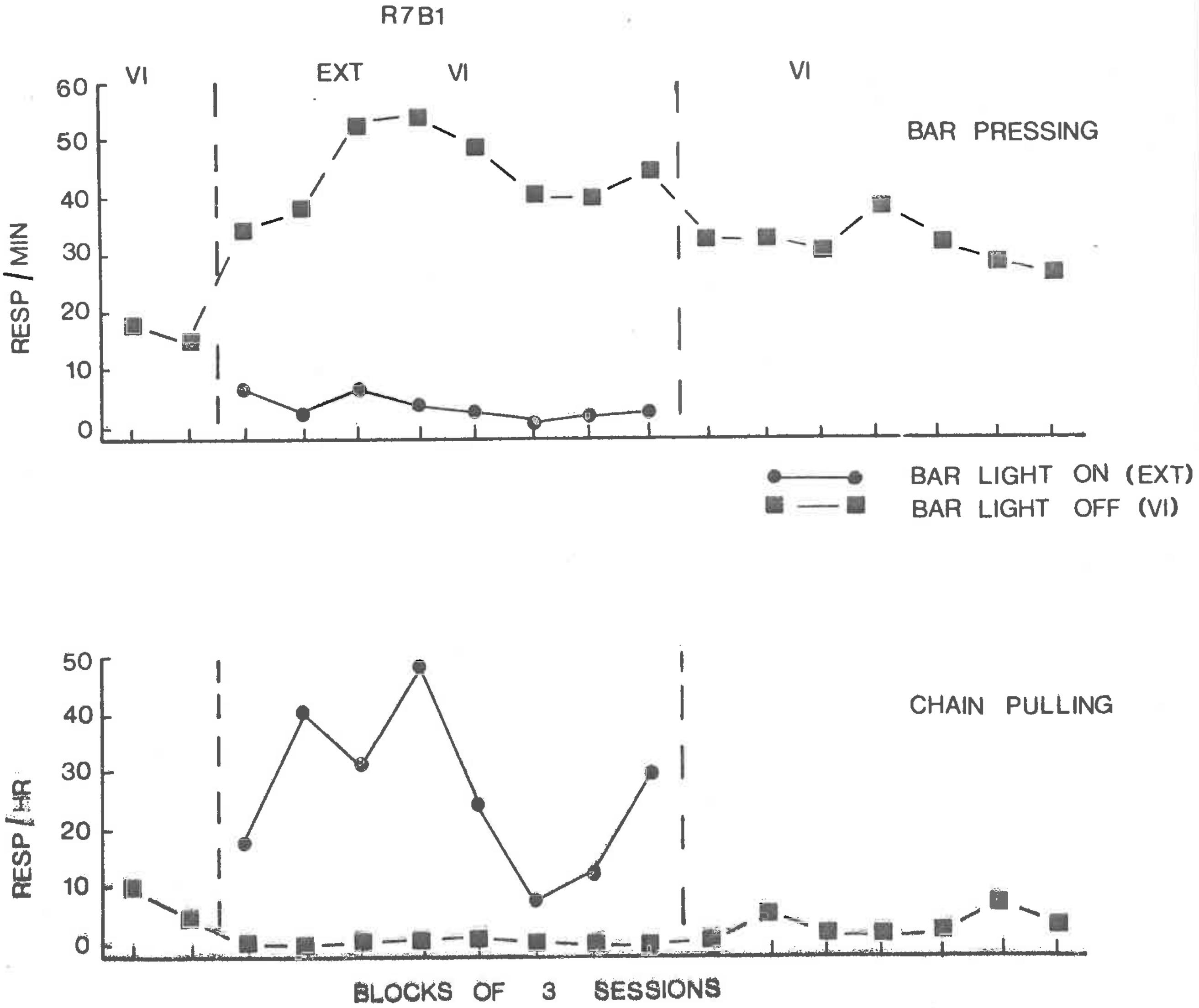

FIGURE 5.12: For R7B1, bar-pressing rate and chain-pulling rate in each component averaged over 3 session blocks. The schedule in operation is indicated.

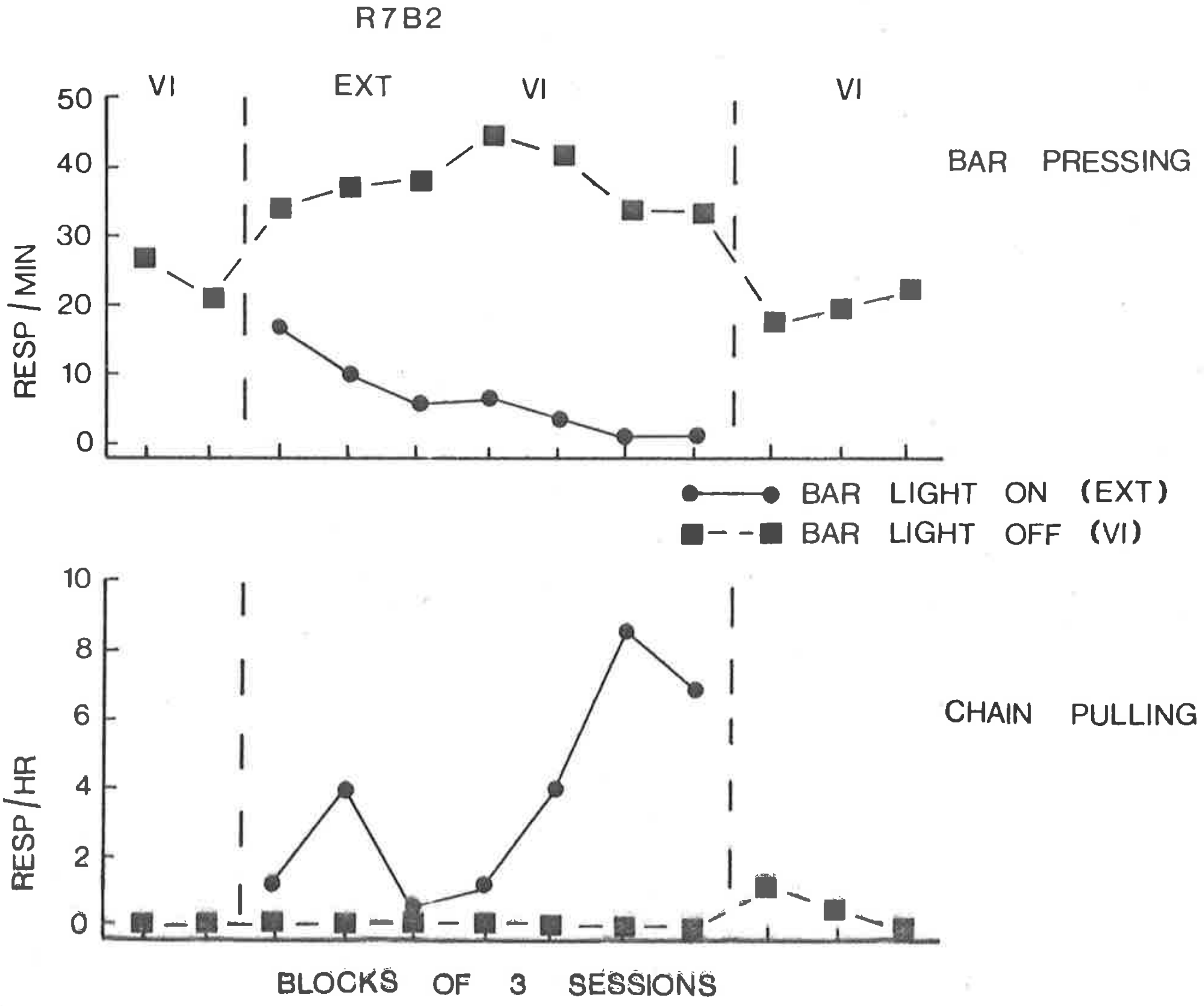

FIGURE 5.12: (contd) For R7B2, bar-pressing rate and chain-pulling rate in each component averaged over 3 session blocks. The schedule in operation is indicated.

between VI and EXT schedules was rapid with only very low response rates during EXT.

The bar-pressing data show both positive and negative behavioural contrast. In both cases the magnitude of the contrast effect initially increased with extended exposure to multiple EXT VI and then decreased slightly. These results strengthen those of Experiment 2 where contrast effects of smaller magnitude were observed. The difference may be accounted for by the difference in procedure, and the associated differences in response rate maintained during EXT components.

Chain-pull rates under VI were extremely low for both subjects. In the case of R7B2 no chain-pulls were recorded when the VI schedule was in operation until the re-exposure to the simple VI. Much higher rates were observed in EXT. These results parallel those obtained in the previous experiment with bar-pressing.

Local rates of bar-pressing and chain-pulling during multiple EXT VI are shown in Figure 5.13. Because of the low rates of chain-pulling averages were taken over all the sessions of exposure to that schedule, while bar-pressing data are averages over the last 5 sessions only. Bar-pressing showed no particular pattern within VI components. There was some tendency for a gradual increase over the first 30-50 seconds and a decrease after that, but with little reliability. If the rate during the first segment is ignored, bar-pressing tended to increase through EXT components - local negative contrast. The initially elevated rate, most evident in the results from R7B1, may have been due to an overshooting effect: a slight delay in reacting to the stimulus change. Such an effect may also account for the relatively low rates in the first segment of VI components.

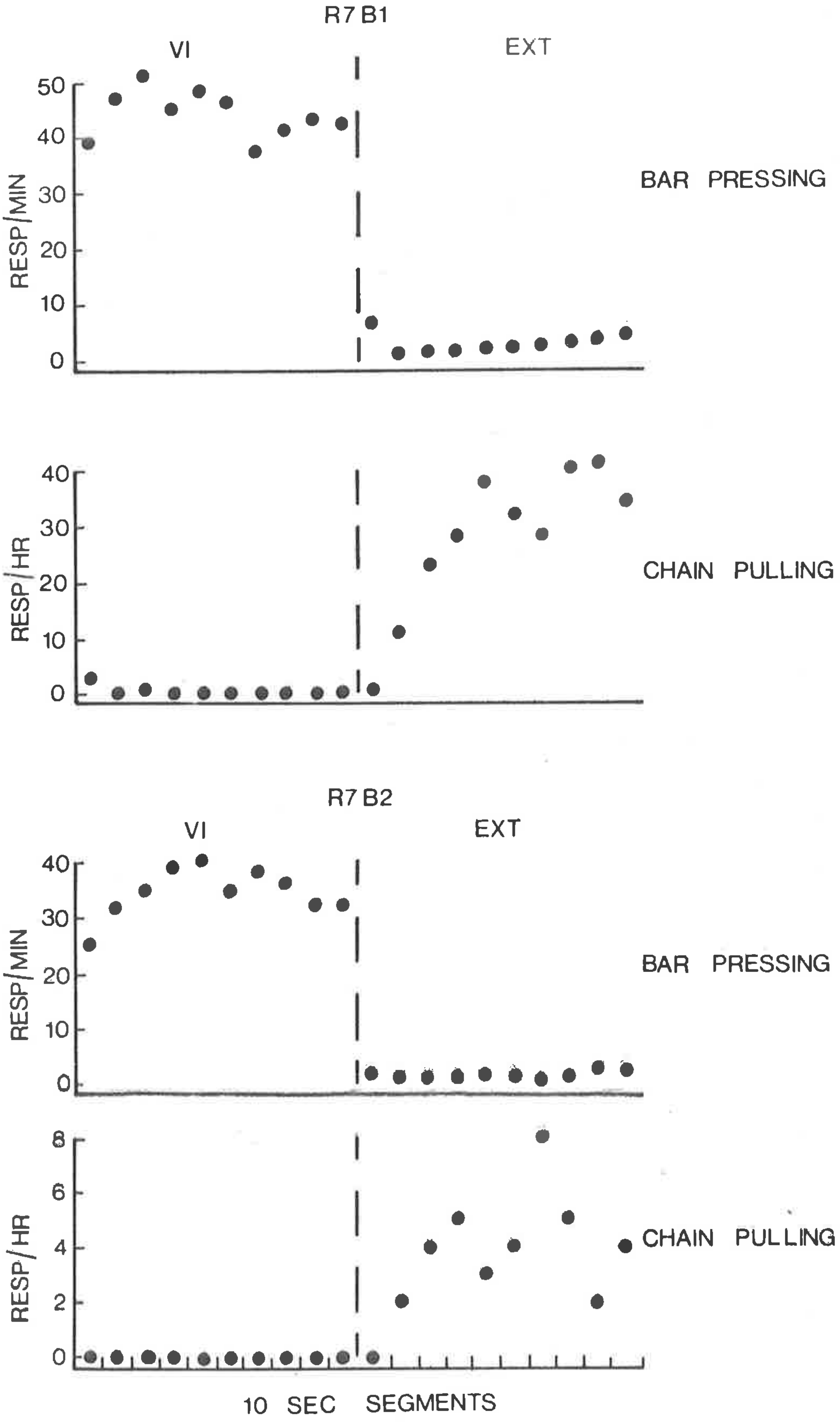

FIGURE 5.13: Bar-pressing rate and chain-pulling rate in each of the ten 10-sec segments dividing each component of the multiple EXT VI schedule. The first half of each graph shows the local response rate pattern in the VI component, the second shows the pattern in the EXT component.

Little can be ascertained from the chain-pull data taken from VI components: R7B2 did not respond at all while R7B1 exhibited a few responses which were confined to the first 30 seconds. The latter could not be regarded as indicative for local positive contrast, however, because of the small number of responses. In both cases there was evidence of local negative contrast. The data from R7B1 were more convincing, particularly because of the greater variability in the data from R7B2. This difference may reflect a difference in the number of responses used to calculate the results in Figure 5.13.

DISCUSSION

The results of this experiment suggest that the high bar-pressing rate observed during EXT in Experiment 4 was independent of the location of the discriminative stimuli. It appears that any alternative response will occur more frequently during EXT than VI components. Whether this is due to simple response competition or not would have to be determined by manipulating response and reinforcement rate independently (but see Section 5.2 for a discussion of the difficulties).

Similarly a local negative contrast effect was obtained with chain-pulling even though responses on this manipulandum had no programmed consequences, and the discriminative stimuli were located on the bar. There is much evidence to suggest that general activity level increases as time to food delivery decreases (e.g. on fixed-time schedules). Killeen (1975) reported a number of experiments using pigeons which demonstrated that the amount of movement within the chamber increased as the time to food delivery was approached, at least for the first part of the interval. Thus the local negative contrast observed in this experiment may simply reflect an increase in general activity level as commencement of the following VI component approaches. The degree to which local positive contrast is a manifestation of the same phenomenon is impossible to assess from the results obtained here because chain-pulling rate was so low in VI components.

While there was evidence for local negative contrast in the bar-press data, local positive contrast was not obtained. The results of Experiment 2 would lead to an expectation of this effect but procedural differences may account for its absence. The subjects in Experiment 5 were exposed to periodicity of the components for a much shorter time than those in Experiment 2. Because the regular alternation of bar-light off and on was not presented to subjects in Experiment 5 until the multiple EXT VI schedule, these subjects may not have received enough exposure to the periodicity. In contradiction to this is the finding of local negative contrast effects, at least in the chain-pulling data.

5.9 SUMMARY OF RESULTS

BEHAVIOURAL CONTRAST

The most obvious conclusion to come from this series of experiments is that the occurrence of positive and negative behavioural contrast is highly dependent upon the discriminability of the stimuli signalling the two components. There was slight evidence of contrast effects in Experiment 1 and none in Experiment 3. The virtual replications of these, Experiments 2 and 4, showed that with better discrimination between the components both positive and negative contrast could be obtained. As mentioned above, such results concur with an analysis which proposes that the degree of interaction between components in a multiple schedule increases with greater discriminability of the stimuli. The results of Experiments 2 and 5 showed that both positive and negative behavioural contrast can be reliably obtained with rats as subjects if the discriminative stimuli are located on the bar. Such positive contrast developed by about the fifteenth session, and was somewhat transient in several cases: the magnitude of the contrast effect diminished with continued exposure to the schedule.

When the components are adequately discriminated, positive and negative contrast can be observed when the discriminative stimuli are located away from the manipulandum. In Experiment 4 contrast effects were observed in the chain-pulling of R73 and R74, although in the latter case positive contrast was largely transient and the negative contrast effect was only small. Thus, neither stimulus location nor similarity between operant and elicited topographies is necessary for the production of contrast. Discrimination between the components (cf. Experiment 3) seems to be the critical variable.

Changes in response rate on the manipulandum on which the discriminative stimuli were located (the bar) were also noted in Experiments 3 and 4. From the latter, bar-pressing rate maintained during VI slightly decreased when the VI was alternated with EXT. While contrast was occurring in the chain-pulling, bar-pressing rate dropped slightly, despite bar-light off being a differential predictor of reinforcement when VI and EXT were paired. Bar-pressing rate was much higher during EXT than either simple VI or the VI paired with EXT. These data suggest an inverse relation between the rate of chain-pulling and the rate of bar-pressing. Because of the poor discrimination, no such changes could be observed in the bar-pressing of Experiment 3. Any changes in response rate in one component were paralleled by similar changes in the other.

Experiment 5, in which bar-pressing was reinforced and the chain was available, yielded results which suggested that the changes in bar-pressing rate in Experiment 4 may not have been due to the location of the discriminative stimuli on the bar. One subject (R7B1) showed a decrease in the rate of chain-pulling maintained during VI when EXT was alternated with it. In the other almost no chain-pulls occurred in VI. Both showed a much higher rate of chain-pulling in EXT than VI. Thus the effects on chain-pulling rate of modifications to the bar-pressing contingencies in Experiment 5 match the effects on bar-pressing rate of changes to chain-pull contingencies in the fourth experiment. This suggests that these effects are independent of stimulus location.

LOCAL CONTRAST

While overall contrast effects are critically dependent on discrimination between components, local contrast occurred independently of such discrimination. Both local positive and local negative contrast were observed in Experiments 1 and 2, despite differences between these experiments in the pattern of overall rate changes. It was suggested that the temporal control which mediates local contrast is largely independent of the control exerted by the discriminative stimuli themselves. Control of the former type was powerful in both experiments, while the latter type was weak in the first experiment and strong in the second.

The results of the second experiment would suggest that similarly strong local contrast should have been observed in

Experiment 5. While evidence of local negative contrast was obtained, local positive contrast failed to occur. It was proposed that temporal control may have been weaker in Experiment 5 because of the smaller amount of exposure of subjects in this experiment to the regular alternation of the stimuli. Such exposure is considerably decreased when the baseline schedule is a simple VI rather than multiple VI VI. Extended exposure of the Experiment 5 subjects to multiple EXT VI would have been required to clarify this point.

Local contrast effects were less reliably obtained in Experiments 3 and 4 where the discriminative stimuli were located away from the manipulandum (the chain). In Experiment 3 the chain-pull data showed evidence of local positive contrast for one subject (R72) and local negative contrast for the other (R71), while in Experiment 4 there was only evidence of local positive contrast in R74's data. Again the discriminability of components did not seem to strongly affect the frequency or strength of local contrast effects. The two observations of local positive contrast are significant in that additivity theory predicts the absence of such effects under the conditions of these experiments.

The bar-pressing data from Experiment 3 were unclear. One subject (R72) showed a tendency to a decreasing rate in the VI component and an increasing rate in the EXT component, while for R71 the only tendency was to a decreasing rate in EXT. The data from Experiment 4 were more consistent: both subjects exhibited a decreasing rate through the VI component and an increasing bar-press rate through EXT. Such patterns are consistent with an hypothesis which proposes that local contrast effects should appear in responding on the manipulandum on which the discriminative stimuli are located. Additivity theory predicts that this should be so in the case of local positive contrast.

Patterns of chain-pulling observed in Experiment 5, where bar-pressing was reinforced, suggested that at least for the increasing rate through EXT, discriminative stimulus location may not be important. Chain-pull rate appeared to increase through EXT for both R7B1 and R7B2. Because of the low rate of chain-pulling in VI components it was impossible to tell if the rate decreased through those components. Thus local negative contrast-like effects can be observed in responding with no programmed consequences on a manipulandum located away from the discriminative stimuli.

5.10 SOME IMPLICATIONS OF THE RESULTS

ADDITIVITY THEORY

The results of the first two experiments contradict Gamzu and Schwartz's (1977) assertion that local positive contrast should not be obtained if rats are employed as subjects. However, if we consider the basic premises of additivity theory then it is clear that such an assertion is unwarranted. These premises state that (a) the discriminative stimuli should be located on the manipulandum and (b) that manipulandum should measure responses elicited by a signal predicting food (as in the autoshaping-omission training paradigm). Clearly the former was satisfied by the apparatus employed in the first two experiments. Experiments by Atnip

(1977) and in this laboratory using the apparatus of these experiments has shown that bar-pressing can be autoshaped. The latter is therefore satisfied as well. The experimental arrangement is thus analogous to that usually employed with pigeons so that we would expect similar results. In particular, consideration of the results of the pigeon experiments, in contradiction to Gamzu and Schwartz, would lead to a presumption of local positive contrast in the first two experiments.

Two experiments which strongly support additivity theory are those of Spealman (1976) and Schwartz (1978). In these, the effects of the stimulus-reinforcer and response-reinforcer contingencies were separated by locating the signal on a separate key. Responding on the operant and signal keys could be separately measured. The results of these experiments have shown that local positive contrast occurs on the signal rather than the operant key, and signal key responding is usually maintained only to the stimulus signalling a higher reinforcement rate. There is evidence suggesting that behavioural contrast may be the result of extra responses to both the signal and operant keys.

In both experiments some subjects were exposed to response-independent schedules so that the only responding measured was on the signal key. The frequency and pattern of responding on the signal key was the same in these subjects as those exposed to response-dependent schedules. According to Schwartz (1978), this group controls for the fact that "the possibility exists that responding on the signal key is in some way influenced by concomitant responding on the operant key". However, the removal of operant contingencies is likely to strengthen any Pavlovian contingencies operating in the situation, as the results of Woodruff _et al_ (1977) would suggest.

An appropriate control is not to remove the operant contingency, but to require different response topographies for the operant and signal manipulanda. By this means any influence on the signal response of the operant response will be minimized. The results of Experiments 3 and 4, in which the discriminative stimuli were located on the bar and chain-pulling was required for reinforcement, differ significantly from those obtained by Spealman and Schwartz.

Most notably, bar-pressing rate was much higher in EXT than VI, and bar-pressing rate tended to decrease in VI when the EXT component was added. Both findings directly contradict any account based on the stimulus-reinforcer contingencies. The within-component patterns of bar-pressing were more consistent with additivity theory. In particular, bar-pressing rate tended to be higher at the beginning than the end of VI components.

Contrast was obtained in chain-pulling when the components were properly discriminated, supporting previous observations (described in the Introduction) of behavioural contrast with discriminative stimuli located off the operant manipulandum. However, the evidence of local positive contrast, although obtained from only 2 of the 4 subjects of Experiments 3 and 4, is particularly damaging for additivity theory. While more evidence needs to be obtained, the data suggest that Pavlovian contingencies are not entirely responsible for the production of local positive contrast. Again it seems as if the same effect can be produced by either stimulus-reinforcer or response-reinforcer contingencies. Which of these controls the behaviour will be determined by the particular experimental arrangement. The province of additivity theory may therefore be circumscribed not by the particular feature or features of contrast which it can explain, as Schwartz (1978) suggests, but by the conditions under which these effects are produced.

A MATCHING ACCOUNT OF CONTRAST

In the sense that the matching law is about operant rather than reflexive behaviour, the additivity theory can be seen to conflict with a matching account of contrast. It was noted in the introduction that an equation of the form of Equation 5.1 must take into account all stimuli in the experimental situation, including the type of reinforcement schedule. With such a generalization the matching account can explain a wide range of experimental data. However, the evidence which supports additivity theory is concerned with behaviour produced by stimulus-reinforcer rather than response-reinforcer contingencies and must therefore fall outside the purview of a matching account.

The results from the experiments reported here, and from others mentioned earlier, suggest that the operation of stimulus-reinforcer contingencies need not be invoked to explain positive and negative behavioural contrast. Although with operant contingencies removed the Pavlovian contingencies may play a role in producing contrast-like phenomena, it seems as though with operant contingencies present, and with no influence of these contingencies on signal manipulandum responding (i.e. the two topographies are different), contrast effects will be observed in operant rather than signal responding.

Thus, when there is an observable response required for reinforcement (even allocation of time to one side of the chamber or the other, as in White, 1978), a generalized matching equation should be able to account for any contrast effects observed.

The results of Experiment 5 suggested that responding to the bar in Experiment 4 was not dependent on the signalling properties of that bar. Rather, the same changes in overall frequency can be observed on any manipulandum, responses on which are not reinforced. Accordingly, such responses assume the status of members of Herrnstein's (1970) category of "other behaviour", corresponding to the reinforcement rate r_e. We should thus be able to derive equations which account for the changes in rate of chain-pulling in Experiment 5.

Let the rate of other behaviour, of which chain-pulling forms a part, be denoted by R_e, associated with reinforcement rate r_e. These reinforcers are not arranged by the experimenter, but are obtained by the animal presumably because the behaviours are self-reinforcing (cf. Premack, 1965). With a simple VI schedule delivering reinforcers at rate r,

$$R_e = \frac{kr_e}{r_e + r} \qquad (5.2)$$

Herrnstein (1970) suggested that to account for contrast effects with a change from VI to multiple VI EXT the aversive properties of EXT must be considered (see Section 2.10). Let the value of this aversiveness be represented by $-r_{ext}$. Then the rate of the operant behaviour, R, will be

$$R = \frac{kr}{r + r_e - r_{ext}} \qquad (5.3)$$

The addition of $-r_{ext}$ to the reinforcement context will account for the observation of positive behavioural contrast. However if Equation 5.2 is simply modified by adding $-r_{ext}$ to the denominator, we obtain the anomalous result that both the operant and other behaviours increase in rate with the addition of EXT. It must therefore be assumed that the aversive properties of EXT selectively reduce the amount of reinforcement available for other behaviour, so that in the VI component of a multiple VI EXT schedule

$$R_e = \frac{k(r_e - r_{ext})}{(r_e - r_{ext}) + r} \qquad (5.4)$$

A comparison of Equations 5.2 and 5.4 shows that chain-pulling rate in Experiment 5 should have been lower during multiple VI EXT than during simple VI. This was confirmed in the subject which exhibited a non-zero chain-pull rate. The bar-pressing in Experiment 4 also conformed to this pattern.

The rate of chain-pulling was much greater in EXT than during simple VI. If we represent the degree of interaction between components by *m*, the rate of chain-pulling during EXT should conform to an equation of the form

$$R_e = \frac{kr_e}{r_e + mr} \qquad (5.5)$$

Comparison of Equations 5.2 and 5.5 shows that these equations predict such an increase.

Hinson and Staddon's (1978) results

Some related findings by Hinson and Staddon (1978) should be mentioned here. In their experiment rats bar-pressed for food on multiple VI VI and multiple VI EXT schedules. In different sets of conditions a running wheel was simultaneously available or not. In agreement with the predictions of the equations above, the rate of wheel running was inversely related to the rate of bar-pressing in the same component (i.e. very high during EXT components, and lower in the VI component of multiple VI EXT than during multiple VI VI). Behavioural contrast was found in both sets of conditions, but its magnitude was much greater when the wheel was available.

They see this result as supporting their account of contrast (see also Staddon, 1977a): the rate of other behaviour will decrease in the unchanged component, because of the greater opportunity for it to occur in EXT, thereby allowing the rate of the reinforced response to increase (positive contrast). However, it is possible that Herrnstein's equations, with some additional assumptions, may be able to account for the greater degree of contrast observed when the wheel was available.

Let r_{e_1} and r_{e_2} represent the non-scheduled sources of reinforcement obtained from components 1 and 2 respectively. Thus the reinforcement context for bar-pressing in the unchanged component will include the term $(r_{e_1} + mr_{e_2})$. When component 2 changes from VI to EXT r_{e_1} will decrease (see above), while r_{e_2} will increase because there will be less competition from bar-pressing in EXT. If the net change in ($r_{e_1} + mr_{e_2}$) is such that there is a sufficiently greater decrease or smaller increase in conditions when the wheel is available, then it can be shown that Herrnstein's equations are sufficient to account for the difference in the magnitude of contrast.

Proof of such an hypothesis requires measurement of the values of other behaviours for the animals. These may be estimated by noting relative time allocated to the variety of responses in which an organism engages (e.g. Roper, 1978), but the data are not available for multiple schedule performance. While there are differences in the two accounts of contrast, both consider the role of other behaviour, shown to be important in the experiments reported here and by Hinson and Staddon.

CONCLUSION

From the results reported here, and the discussion of these and other experiments, it is reasonable to conclude that multiple schedule performances generated under a wide range of experimental conditions can be accounted for by a formulation similar to Herrnstein's. Two points in particular may be noted. Firstly, the evidence of reflexive responding under conditions in which relative reinforcement rate varies from 0.5 is not entirely contradictory to an account relying on operant behaviour, since the operant contingencies seem to at least influence this 'reflexive' behaviour in some way. Secondly, the way in which time is allocated to the reinforced class of responses and to all other behaviour should be more closely examined. This accords with a view of multiple schedules as providing choice between the reinforced class and other behaviour under two (or more) sets of contingencies.

However, a considerable amount of the data reported here falls outside the purview of matching: the within-component gradients of response rate. In the next chapter a means will be described by which Herrnstein's equation for absolute response rates may be modified to account for local response rates. It may then be possible to give a tentative description of the type of equations which may be used to account for local positive and local negative contrast. This formulation will again emphasize allocation of time between reinforced and other behaviour.

CHAPTER 6

QUANTIFYING LOCAL RESPONSE RATE GRADIENTS

6.1. INTRODUCTION

While an account of behavioural contrast based upon relative rates of reinforced and other behaviours can be developed, local contrast effects remain outside the purview of Herrnstein's equations. Yet it seems reasonable to assume that a similar type of analysis may be used to explain both local and behavioural contrast. One important difference between the two phenomena, noted in Chapter 5, was the dependence of the former on stimulus changes and of the latter on stimulus effects per se. Local contrast may be conceived in terms of gradients of local response rate centred around the stimulus changes: an excitatory gradient around the change from EXT to VI and an inhibitory gradient around the VI to EXT change. The idea that local contrast is indeed a product of generalization from such changes will be considered later.

Firstly, however, we will consider how Herrnstein's equation for absolute response rates (Section 2.9.1) may be modified in order to account for changes in local response rate. Rather than use data from multiple schedule performance to develop the model, we will use the behaviour generated by the simpler FI schedule. This shares with the multiple VI EXT schedule the characteristic of a period of non-reinforcement followed by a period of reinforcement availability. In the multiple schedule instance, reinforcers are arranged by a VI schedule and this period is terminated according to elapsed time rather than reinforcement. For FI schedules reinforcement is arranged by an FR1 contingency and the period of availability is terminated after the first reinforcement.

Although there are considerable differences between the two, an equation which can explain FI behaviour should, in principle, be able to be adapted to account for local negative contrast in multiple VI EXT schedules: the similarity of the schedules suggests similar controlling variables. The analysis will be further extended to consider local positive contrast.

6.2. FIXED INTERVAL BEHAVIOUR

Following Ferster and Skinner (1957), the fixed-interval schedule is defined such that after a fixed period of time has elapsed since the presentation of a reinforcer, the first response is followed by a reinforcer, which begins the next interval. The most pervading characteristic of responding under the fixed-interval schedule is the development of "scalloping" in the cumulative record of the subjects' behaviour. This was first reported by Skinner (1938) as "deviations of a third order".

Underlying this pattern is a smooth increase in response rate through the interval to a rate close to asymptotic level at the end. Scalloping is independent of the length of the interval (Ferster and Skinner, 1957; Dews, 1970) and of the reinforcer used (Dunn, Foster and Hurwitz, 1971; Morse and Kelleher, 1966) and is maintained even if reinforcers are omitted occasionally (Dews, 1966).

A variant of this pattern which is sometimes observed is the break-and-run pattern (Cumming and Schoenfeld, 1958): a very low or zero response rate early in the interval which abruptly changes to a high, approximately constant response rate. The location of the point of transition (the breakpoint) within the interval varies considerably from interval to interval. Consequently, the pattern revealed by averaging responding over a number of intervals, each of which shows a break-and-run pattern, is a smooth increase in rate through the interval. Dews (1978) has presented data which suggest that even when the pattern would be described as break-and-run, there is still a gradual but significant increase in response rate after the breakpoint. Thus the averaged curve may give a reasonable representation of behaviour in individual intervals even when the characteristic pattern is break-and-run. It is with the smooth, averaged curve that we will be concerned here.

6.3. DERIVATION OF THE EQUATION

Herrnstein's (1970) equation describing the relation between absolute response rates and reinforcement rates in simple variable-interval schedules was discussed in Section 2.9.a. It takes the form

$$R = \frac{kr}{r + r_e} \qquad (6.1)$$

where R is the response rate, r the reinforcement rate and k and r_e are parameters interpreted as asymptotic response rate and rate of reinforcement for other behaviour, respectively.

Altering this equation in order to account for local response rates within FIs requires that the effects of the two reinforcement rates be modified according to some function of elapsed time within the interval. The effects of the reinforcement which terminates the interval should increase with elapsed time and the effects of reinforcement for other behaviour should correspondingly decrease. Dews (1970) provides some information as to the nature of this function. He demonstrated that the pattern of responding within intervals is unaffected by FI size. It is therefore relative rather than absolute proximity to reinforcement which is important in determining response rate.

The modulating effects of relative proximity may be best expressed not by the proportion of the interval which has elapsed, but by some function of this value. Since a power function with coefficient 1.0 will add only one parameter and provide a range of relations between elapsed time and reinforcement effects it may be most appropriate as a first approximation. Thus with an FI of duration T, response rate at time t will be

$$R_t = \frac{k\left(\frac{t}{T}\right)^n r}{\left(\frac{t}{T}\right)^n r + \left(1 \left(\frac{t}{T}\right)^n\right) r_e} \qquad 0 \leqslant t \leqslant T \qquad (6.2)$$

In accord with Herrnstein's (1974) interpretation of Equation 6.1. the total amount of behaviour occurring at any time, measured on a common scale, is constant and equal to the value of <u>k</u>. This behaviour is divided into responses which are members of the class which can be reinforced (e.g. bar-presses) and the class of all other behaviours. The former increase in rate through the interval from 0.0 to k according to Equation 6.2. Members of the latter class decrease in frequency in a manner which maintains the constancy of the total amount of behaviour over the interval.

Fitting the equation requires a set of local response rates with corresponding elapsed times within the interval. The value of r may be arbitrarily set to unity for simple FI schedules with a single reinforcement terminating each interval and the values of n, k and r_e obtained by means of a non-linear curve-fitting procedure.

6.4. EXPERIMENTAL VALIDATION

Two criteria must be met in order to show that Equation 6.2. is a useful descriptor of FI performance. Firstly, across the range of different curves obtained the equation must account for a large proportion of the variance in the local response rates with no consistent deviation of the fitted line from obtained values. Secondly, the parameters of Equation 6.2 should be independent of FI duration. That is, neither k, r_e or n should be a function of T, since this would indicate that T should enter the equation elsewhere than to indicate the relative proportion of the interval which has elapsed. It is the aim of this experiment to find whether these criteria are met and thus whether this equation may be regarded as a valid means of describing the within-interval pattern of FI responding.

Each subject was exposed to a single FI duration in order to minimize any transfer effects. Durations ranged from 5 to 200 secs. Additional data were obtained from the results of an experiment by Dews (1978) in which the FIs were of much longer duration and rhesus monkeys rather than rats were used as subjects. The generality of Equation 6.2 may be extended if it is found to account well for these data as well as those from the experiment here.

Method

Subjects. Twelve six-month old male Wistar hooded rats served as subjects. Each had experience of continuous reinforcement, extinction and several sessions of exposure to either a fixed-ratio or a variable-interval schedule. During the experiment access to food was limited to the hour after the end of each session. Water was freely available in home cages. Housing was in individual cages in a temperature and humidity controlled room with a 12-hour day/12-hour night cycle.

Apparatus. All experimental chambers measured 22 cm x 22 cm x 21 cm high. In each a 5 cm long bar, which could be operated by a force of 0.10 N, protruded 0.90 cm into the chamber. This was situated in the middle of one panel, 9.5 cm above the floor. Below it was a magazine into which 45 mg of food pellets could be deposited. Each chamber was enclosed in a sound resistant shell with an exhaust fan in one wall and a white noise generator for masking external sounds. Control of the experiment and recording of data was performed by a PDP-11 computer.

Procedure

No preliminary training was required since all subjects had previous experience of bar-pressing for food reinforcement. Two subjects were assigned to each of the six FI schedules: 5, 10, 20, 50, 100 and 200 secs duration. Sessions lasted until the subject had received 60 reinforcements, or 30 in the case of subjects on the FI 200 sec schedule. They were run seven days per week.

Exposure to the schedule was terminated when the coefficient of variation, calculated over 3 consecutive sessions, was less than 0.05 for both total number of responses emitted and session duration. An additional requirement was that the pattern of responding revealed by inspection of cumulative records appeared constant over these 3 sessions. The number of sessions taken to reach this criterion varied from 11 to 22.

To obtain local response rates each interval was divided into a number of segments, and the number of responses in each segment summed over all the intervals of the final 3 sessions. The number of segments was varied according to FI size so that each segment occupied approximately the same amount of total session time, but with a minimum of 10 segments. There were 10 segments for intervals of 5, 10 and 20 secs, 25 for 50 sec intervals and 50 for intervals of 100 and 200 secs.

Results

Equation 6.2 was fitted to the data from this experiment and to that obtained by Dews (1978). Values for the latter were derived by estimation from the figure in that report. The two subjects were rhesus monkeys and the FI schedule was of 1000 secs duration.

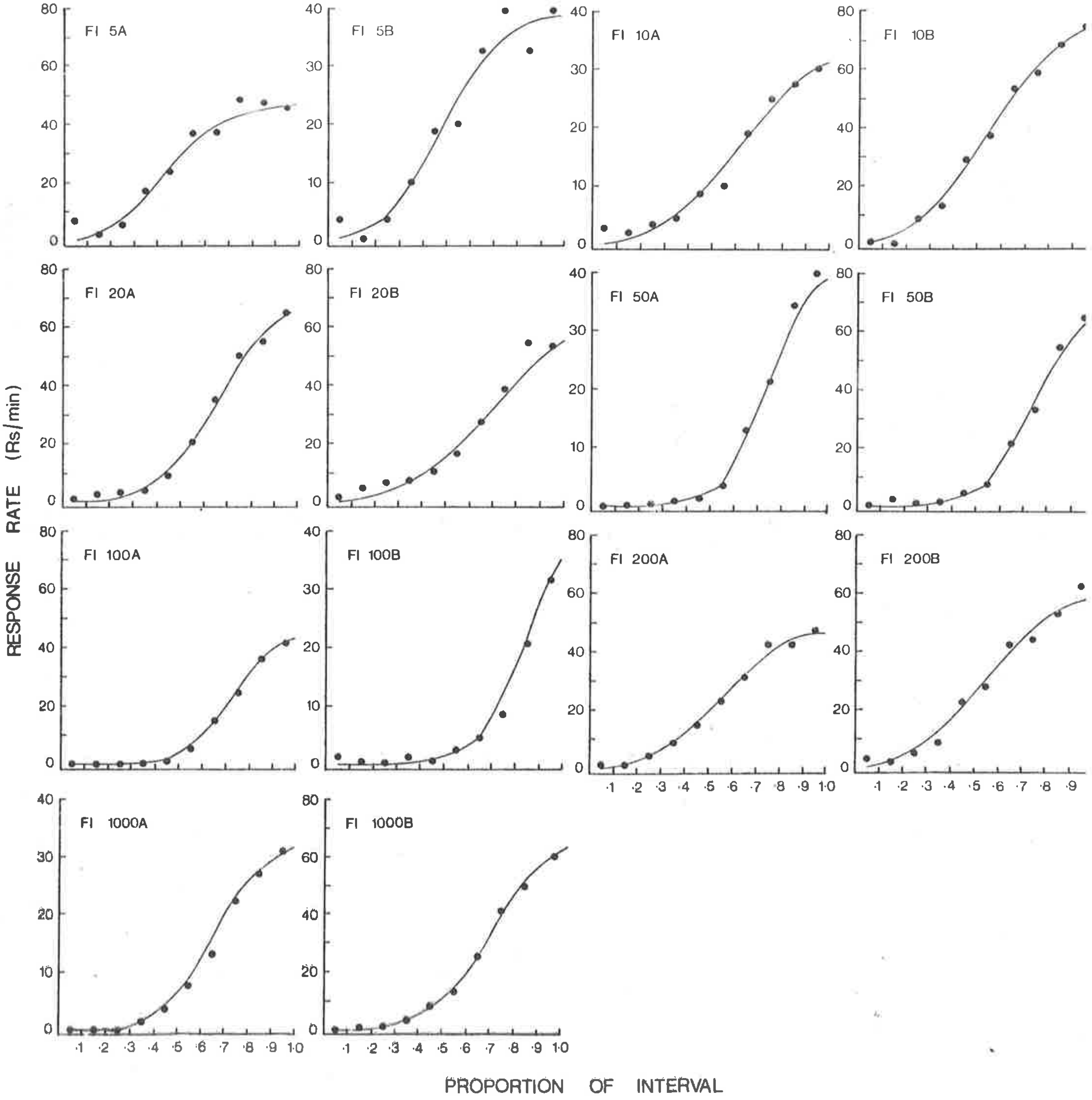

FIGURE 6.1: Rate of responding in each of the ten segments dividing each interval. The curves are fit of Equation 6.2. Schedule size (in seconds) is indicated on each graph.

TABLE 6.1: Values of the parameters from and proportion of the variance accounted for (r^2) by each of the fitted lines of Figure 6.1.

	FI 5		FI 10		FI 20		FI 50		FI 100		FI 200		FI 1000	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
K	48.3	39.4	32.3	77.3	66.8	59.1	40.4	68.2	44.6	36.6	48.5	60.4	32.7	64.8
n	3.49	3.53	3.01	2.74	4.68	2.18	7.37	5.93	7.34	7.48	3.50	3.15	5.07	4.42
r_e/r	.06	.08	.29	.23	.14	.75	.11	.20	.09	.30	.14	.15	.16	.25
r^2	.968	.960	.975	.996	.995	.991	.996	.996	.996	.987	.989	.986	.997	.997

Obtained values and fitted lines are presented in Figure 6.1, with corresponding parameter values and proportions of variance accounted for by the fitted lines in Table 6.1. In order to improve clarity only 10 points were plotted in each graph of Figure 6.1. In all cases Equation 6.2 provided a good approximation to obtained values, with over 99% of the variance accounted for in most instances. The poorest fit occurs for the 2 subjects exposed to FI 5 sec schedules. Performance on such short duration schedules can deviate from the general pattern of FI behaviour. This is exemplified here by the fact that for animals exposed to FI 5 sec and FI 10 sec schedules response rate is higher in the first than the second segments.

The only deviation of the fitted line from observation which is consistent among a large proportion of subjects is underestimation of response rate in the first 2 or 3 tenths of the interval. These deviations are generally of small magnitude, contributing little to the error variance. Consequently they do not justify modification to Equation 6.2.

Most of the variation in the parameter values shown in Table 6.1 can be attributed to inter-subject variability. As FI duration increases from 5 to 1000 secs there is no consistent change in the values of any of the parameters. All parameters thus appear to be independent of FI size.

Discussion

Equation 6.2 provided a very good account of the averaged pattern of FI responding despite considerable variation in underlying response patterns within individual intervals.

Inspection of cumulative records revealed that a number of animals were exhitibing well developed break-and-run patterns (e.g. FI 50 A), while others more closely approximated the smooth increase in rate described by the scallop (e.g. FI 200 B).

Two previous attempts at quantifying FI responding may be mentioned here. Schneider (1969) contended that the break-and-run pattern was the characteristic mode of responding after extended exposure to FI schedules. In order to preserve this pattern in the averaged curve, Schneider used the breakpoint rather than the beginning of the interval as the origin for averaging. A pattern of responding is then characterised by two response rates.

This approach may be criticised on several grounds. Firstly, it ignores the variability in the position of the breakpoint in each interval. Secondly, as mentioned above, Dews' (1978) data suggested that there is a gradual but significant increase in response rate after the breakpoint. In addition, Schneider's method will result in the averaged curve extending over a time period longer than the FI length. Thus, there are difficulties associated with an analysis in terms of two constant response rates.

Killeen (1975) has described FI responding mathematically, but by fitting the left half of normal curves to the averaged pattern of responding within intervals. The equation he used was

$$R_t = H\ e^{-\left(\frac{t/T - M}{S}\right)^2} \qquad (6.3)$$

where e is the base of natural logarithms and H, S and M are parameters whose values are obtained by means of a curve-fitting procedure. Killeen interpreted the parameter H as the theoretical maximum response rate, similar to the parameter k of Equation 6.2. M is the psychological judgement of the duration of the interval and S indexes the degree of curvature (c.f. the discussion of n, below).

Killeen reanalysed some data from several experiments which employed FI schedules and found Equation 6.3. to account for a large proportion of the variance in local response rates in each case. In this sense there is little to choose between this and Equation 6.2. It may be noted that Killeen found some correlation between H and T, whereas there was no correlation between k and T in this experiment. While further investigation of this matter is needed, it suggests that H may not have the same cross-situational generality as k. Equation 6.2 also has some advantage in sharing common assumptions with a view of the effects of reinforcement derived from consideration of a wide variety of behaviour maintained by schedules of reinforcement (c.f. de Villiers and Herrnstein, 1976, and Section 2.9).

Equation 6.2. assumes that the effects of scheduled reinforcements increases through the interval according to the function $(t/T)^n$. Two mechanisms, temporal generalization and delayed reinforcement, can be proposed to account for this function. According to the former, $(t/T)^n$ represents the shape of the generalization gradient which extends through the interval and peaks with the reinforcement terminating the interval. Such an hypothesis is in accord with Staddon's (1972) conception of relative proximity and his analysis of FI behaviour. On the other hand, both

Dews (1970) and Morse (1966) have considered delayed reinforcement an important mechanism governing FI responding. Thus $(t/T)^n$ may be a decay function representing the decreasing effects of reinforcement on responses more remote from the end of the interval. Jenkins (1970) presented a third view: that relative proximity effects are not reducible to either temporal generalization or delayed reinforcement. It may therefore be appropriate to regard $(t/T)^n$ simply as the relative proximity function, the mechanism of which remains undetermined, and to note that $\underline{n}$ is an index of the sharpness with which response rate changes through the interval. The smaller the value of $\underline{n}$, the more gradual is the change in response rate.

The interpretations of the parameters $\underline{k}$ and r_e follow from Herrnstein's (1974) analysis of the properties of Equation 6.1. Obtained values of $\underline{k}$ accord with the view of this parameter as representing asymptotic response rate since in general they were slightly higher than the last measured local response rate. For each animal values of r_e/r were less than 1.0, indicating that the reinforcing value of other behaviours was less than the value of food reinforcement. If r_e/r were greater than 1.0 the local response rate functions would be convex rather than the concave functions shown in Figure 6.1. Such curves have been obtained, for example by Catania and Reynolds (1968).

Equation 6.2 may also be applied to the behaviour produced by FT schedules, where reinforcement is independent of any response. Staddon and Simmelhag (1971) defined two classes of behaviour which occur in periods between food deliveries. Terminal responses change in rate through the interval in a similar manner to the operant response in an FI schedule. Their pattern could therefore be described by Equation 6.2. Interim responses decrease in rate through the interval in a manner similar to that proposed for the class of other behaviours in FI schedules. As long as a class of terminal responses (e.g. head in food magazine, pecking wall) can be identified, Equation 6.2 can be used to describe the behaviour induced by periodic schedules of non-contingent reinforcement.

The equation derived in Section 6.3 has proved to be successful in describing behaviour generated by FI schedules. The criteria mentioned at the beginning of this section, goodness of fit and independence of the parameters from FI duration, have been adequately met. The assumptions Herrnstein made in the derivation of Equation 6.1, and the assumption made about the effects of relative proximity to reinforcement, seem sufficient to account for the type of local response rate patterns generated by FI, and perhaps FT schedules. In the next section we will consider an extension of this analysis to local response rate patterns in multiple VI EXT schedules.

6.5 EXTENSION TO LOCAL CONTRAST

A response rate pattern generated by a multiple EXT VI schedule, similar to some found in the experiments of Chapter 5, is diagrammed in Figure 6.2. Response rate gradually rises from a near-zero level through EXT, then increases abruptly with the stimulus change and then decreases slowly again through the VI component. Both local positive and local negative contrast are illustrated in this pattern

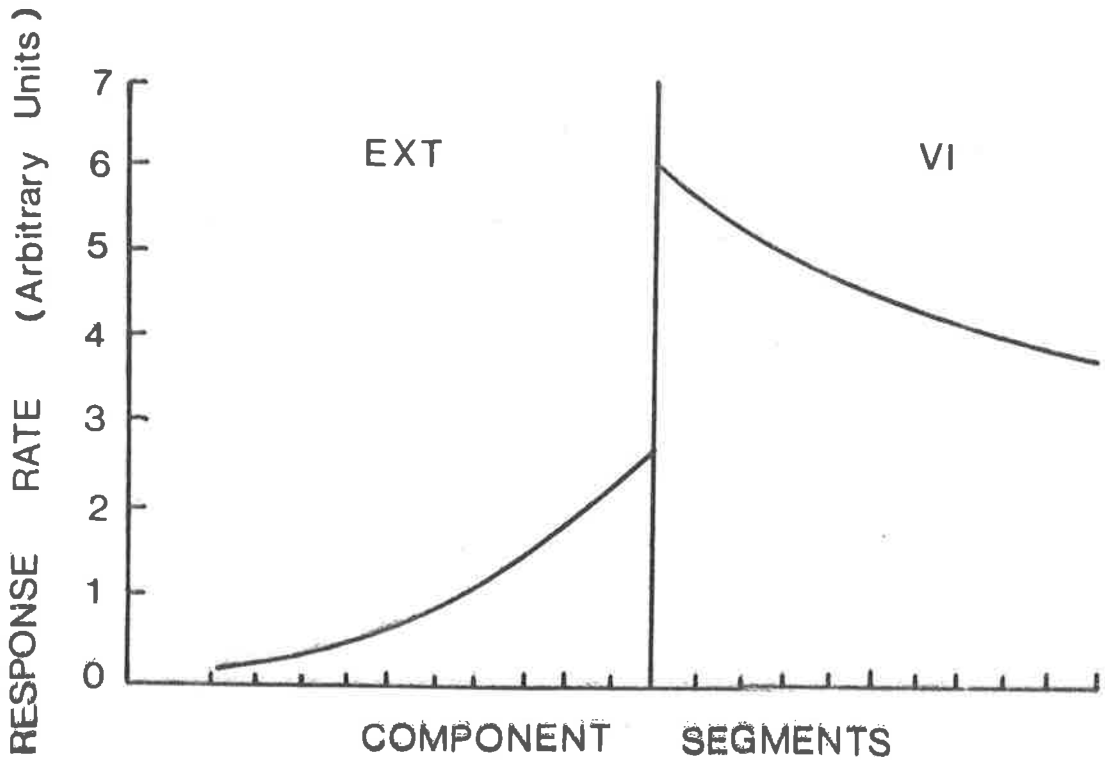

FIGURE 6.2: Hypothetical local response rate pattern in each component of a multiple EXT VI schedule.

of responding. The conditions under which such a pattern is exhibited were discussed in Chapter 5. This section will be concerned with means of describing this pattern using equations of the form of Equation 6.2. One point noted in the previous chapter, the dependence of local contrast on stimulus changes rather than stimulus effects *per se*, will be of particular importance here.

It is clear that the pattern of responding during the EXT component is very similar to the FI behaviour which Equation 6.2 was used to describe. The event terminating this interval is the stimulus change signalling the end of the EXT component and the beginning of the VI component. Since this change indicates the beginning of a period in which reinforcement may be obtained according to a VI schedule, it is likely to acquire conditioned reinforcing properties. In this sense the EXT component is an interval terminated by the presentation of a conditioned reinforcer.

It was stated in the previous section that even when there is no response-reinforcer dependency some terminal response is usually induced by the periodic delivery of a reinforcer. By definition, terminal responses increase in rate through the interval between reinforcements. Here the reinforcer is a stimulus change which signals the availability of food. Clearly, we would expect the terminal response for the EXT component to be the same as the response required for food reinforcement, as is the case.

The value of $\underline{r}$ in Equation 6.2 will be dependent upon the secondary reinforcing value of the stimulus change, which will in turn be a function of the reinforcement rate associated with the VI stimulus. Thus the value of $\underline{r}$ can only be determined empirically, with reference to some standard reinforcer such as a food pellet, but if we wish only to find r_e/r, $\underline{r}$ can assume an arbitrary value.

The decrease in response rate through the VI component may be similarly explained by decreasing proximity to the EXT to VI stimulus change as the component progresses. Thus, if we consider the value t/T in Equation 6.2 as relative distance to or from reinforcement, this equation will predict a declining response rate following the EXT to VI stimulus change. However, this effect is in addition to the reinforcement arranged according to the VI schedule. Responding in the VI component is maintained by the combined effects of food reinforcement (constant through the component) and excitation from the EXT to VI stimulus change (decreasing through the component). The right-hand side of Figure 6.2 can be understood from this perspective.

While similar mechanisms may account for local positive and local negative contrast, the values of the parameters of Equation 6.2 may not be the same for both EXT and VI components. For example, we would expect much more reinforcement to be obtained from other behaviour in EXT than during VI. The value of $\underline{n}$ may also be different for the two components. A description of the effects of the EXT to VI stimulus change may therefore require one curve for the effects in EXT and one for the effects in VI.

The role of stimulus change in the production of local contrast has been discussed solely in terms of excitatory effects. However, we could have also considered the inhibitory effects of the VI to EXT change. Without knowledge of response rates maintained by a prior multiple VI VI schedule these terms can only be used relatively. Thus "excitatory" simply denotes the effect of the EXT to VI change relative to the VI to EXT change.

This account of local contrast has been admittedly speculative. An equation was derived which proved useful in describing FI behaviour. Applying this to gradients of response rate within components of a multiple EXT VI schedule required additional assumptions, some of which lack strong empirical support. For example, it is not clear that a conditioned or secondary reinforcer is able to support the amount of responding generated during EXT components. Some of this responding may be due to failure to adequately discriminate the components of the multiple schedule. This is strongly suggested when the response rate at the beginning of EXT components is relatively high. In such instances an extra parameter may have to be introduced so that the relative proximity function is a power function with a variable coefficient, rather than a coefficient of 1.0.

Nevertheless, some benefit can be derived from such speculation. The results from experiments in Chapter 5 strongly suggest that local contrast is dependent upon stimulus changes rather than stimulus effects <u>per se</u>. By suggesting how an account of local contrast can be derived with this basic assumption we can at least begin to test various hypotheses in a rigorous, mathematical fashion. Such speculation may also help assimilation of the various theories of contrast. For example, if the behaviour resulting from the effects of stimulus changes, and described by variations of Equation 6.2, were shown to resemble reflexive responding under certain conditions, then some common ground could be established for additivity theory and Herrnstein's account. Such problems remain as topics for future research, however.

CHAPTER 7

GENERAL DISCUSSION

7.1. SOME CONCLUSIONS ON THE GENERALITY OF HERRNSTEIN'S EQUATIONS

The research reported here was concerned with several issues pertaining to the generality of Herrnstein's equations for multiple and concurrent schedule performance. Clearly, there are many such issues and these experiments cover only a small range of the areas which need to be researched in order to establish the generality of the equations. Nevertheless, in each case the results generated will help to increase our understanding of the effects of reinforcement on behaviour.

One conclusion from Chapter 3 was that the allocation of behaviour seems to be less sensitive to the distribution of reinforcements across alternatives when choice is between two responses of different topography, rather than two of the same form. Both response and time ratios tend to undermatch reinforcement ratios in such circumstances. The degree of undermatching found in previous experiments, and those reported here, suggests that matching does not generalize to concurrent performances when there is an asymmetry in response form. Further research may show that the extent to which matching is approximated may depend upon the degree of similarity of the responses. Another factor which must be taken into account when considering scaling of response preference is the type of reinforcer contingent upon the responses. The degree of preference for one response over another was shown to vary with reinforcer type.

Perhaps the most obvious restriction on the generality of matching is the need to employ a COD of sufficient length.

While variations in the sizes of both CORs and CODs have similar effects on some aspects of concurrent performances (e.g. increased local response rate, decreased changeover rate with larger CORs and CODs), in many other instances the effects are diverse. In particular, there is a marked difference in the manner in which local response rate changes with post-changeover time. Coupled with such differences is the fact that matching is found across only a small range of COR values. One implication to follow from these data is that the relations between response ratios and reinforcement ratios, and between time ratios and reinforcement ratios, are dependent upon the local response rate patterns generated by the particular contingencies. This had already been suggested in Section 2.4.7., following consideration of a number of experiments concerned with the generality of matching.

Some support was found for Herrnstein's account of multiple schedule performance in Chapter 5. Pavlovian contingencies were seen to play a role in generating contrast effects only to the extent that the experimental arrangement allowed. While this role needs to be more exactly defined, Herrnstein's equations seem sufficient to account for a broad range of contrast effects. However, the concept of reinforcement or value should be generalized to include factors such as preference for different schedule types.

Again it was suggested that more emphasis be placed upon consideration of the particular patterns of responding generated by multiple schedules. As an example of such an approach, a means was proposed by which Herrnstein's equations could be modified so as to describe local response rate changes. A complete account of schedule-controlled behaviour should include quantification of the effects of both relative reinforcement rate and relative proximity to reinforcement.

One important implication to follow from the research reported here, and consideration of the extant literature, is that the effects of reinforcement at the molar level cannot be entirely separated from its molecular effects. Here the concern has been with the degree to which matching is approximated (at the molar level) and local response rates (at the molecular level).

7.2. TIME ALLOCATION, LOCAL RESPONSE RATES, AND MATCHING

The range of contingencies over which matching provided a good description of the relation between behaviour and reinforcement rate was discussed in Chapter 2. One important issue was whether both time matching and response matching are both valid relations or whether one of these seemed superior to the other in its ability to describe the data. It may be that only one of these measures of behaviour, time allocation or response rate, exhibits the simple orderly relation with reinforcement rates described by matching.

Rachlin (1973) had proposed that time matching was the fundamental relation and response matching derivative. The critical assumption of this argument was that local response rate was equal across the alternatives of a concurrent schedule. However, a review of the results from experiments in which concurrent VI schedules were employed with a COD showed this not to be the case. Rather, local response rate was dependent upon relative reinforcement rate: it was higher for the alternative associated with the lower reinforcement rate. A reasonable conclusion from these experiments is that time ratios closely approximate reinforcement ratios, but response ratios undermatch reinforcement ratios.

Unfortunately, such a generalization does not hold when changeover contingencies other than the COD are employed. With a COR required for switching between alternatives of a concurrent schedule, local response rate is greater for the alternative arranging the higher reinforcement rate. If the COR size is such that time ratios match reinforcement ratios, then response ratios will overmatch reinforcement ratios. With CORs greater than one or two responses, time matching provides a reasonable description of the data, with deviations principally in the direction of overmatching.

Two other changeover contingencies, time-out and electric shock, were discussed in Chapter 2. With concurrent VI schedules, and either of these changeover contingencies, time and response ratios may undermatch, match or overmatch reinforcement ratios, depending on time-out length or shock magnitude. However, in both instances time ratios had a much narrower range than response ratios, and therefore more closely approximated reinforcement ratios. Whichever changeover contingency is used, from the four considered here, time matching is a more valid generalization than response matching. In addition, whether response ratios undermatch or overmatch reinforcement ratios is dependent upon the particular changeover contingency. Equivalently, the changeover contingency will determine the way in which local response rates are influenced by relative reinforcement rate.

These results point to the greater generality of time matching, at least with respect to variations in the contingencies on switching between alternatives. Matching is, of course, a molar phenomenon. It describes the relation between variables averaged over considerable periods of time. Clearly, both time allocation and response rate may not necessarily exhibit the same degree of regularity at the molar level. The data suggest that the molar phenomenon may be the allocation of time between alternatives. The relation between response ratios and reinforcement ratios will then be determined by the time ratio-reinforcement ratio relation and the local response rate pattern. It is this pattern which may require analysis at the molecular level for a greater understanding to be reached.

One clear limit on the generality of time matching has been revealed by experiments in which concurrent schedules arrange reinforcements for responses of different topography. Both response ratios and time ratios undermatch reinforcement ratios. The type of generalization which will emerge from future research on this topic is not clear. Perhaps it may be shown that the effect of reinforcements obtained on one schedule on responses in the other declines as the two responses diverge in topography. The equations for concurrent performances with different response requirements would then be similar to those for multiple schedules.

The other important point revealed by these experiments is that local response rate is also influenced by the topography of the response involved. In general, it seems as though the preferred response is emitted at a higher rate within the time period the organism allocates to that alternative. Thus local response rate is dependent upon both relative reinforcement rate (the nature of this relation depending on the particular changeover contingency) and the topography of the response. Although no data are available which can test the proposition, it seems likely that the type of reinforcer maintaining the behaviour will also influence local response rate. Certainly, the relation between the overall rates of two different responses is modified by a change in reinforcer type. Local response rates will only be independent of the type of reinforcer if relative time is modified to exactly the same degree.

An organism exposed to a concurrent schedule can be conceived of as allocating time to each of the two arranged alternatives. The time allocated to each of the alternatives is then divided into time spent responding and time engaged in other behaviour. This distribution will determine the local response rate for that alternative. One means of looking at this more directly is through multiple schedule performance. Since the time base for calculating response rates is the total time for which the component is in operation, the local response rate for each component is the same as its overall response rate. The organism is only able to adjust response rate in each component by changing the relative amount of time allocated to reinforced and other behaviour.

An analysis of multiple schedule performance in terms of this distribution was considered for behavioural contrast in Chapter 5 and local contrast in Chapter 6. Clearly, a number of modifications have to be made if this type of analysis is to be applied to concurrent schedule performances. In particular, the regular alternation of components of fixed length does not occur with concurrent schedules: the organism controls switching between alternatives. Yet, the changes in local response rate with post-changeover time, observed in Section 4.5, are potentially explicable in the same terms as those used with respect to multiple schedules.

Such an endeavour signals a change in emphasis from molar to molecular contingencies. A molar analysis may be fruitful in revealing the regularities which manifest themselves at that level, as Dews (1970) has pointed out with respect to FI behaviour. The danger lies in the degeneration of a molar analysis into a catalogue of deviations from some standard. The amount of predictive power added by each new finding or catalogue entry will be relatively small.

It is this danger which we should be careful to avoid in research on matching, particularly when examining the generality of the phenomenon. The example provided by the extension of matching to concurrent performances with the changeover contingencies other than the COD has already been mentioned. It was suggested that a greater emphasis on isolating the variables controlling local response rate patterns may result in a better understanding of the deviations from matching. The utility of a molecular analysis was also pointed out in Section 2.4.4, where experiments employing concurrent schedules other than VI were considered. Evidence was reviewed which suggested that at least with concurrent FI VI and concurrent FI FI schedules, matching is dependent upon the particular local response rate pattern generated.

Thus, an understanding of the variables controlling the patterns of response rate, and the relation of these patterns to matching may add more predictive power than simple cataloguing of relations between relative response rates and relative reinforcement rates. This is made necessary by the somewhat limited generality of response matching. In particular, that it is confined to concurrent performances where a COD of sufficient length is employed and the schedules are of certain types. Time matching appears to have greater generality, suggesting that the allocation of time may be more susceptible to a molar analysis than the distribution of responses between alternatives.

7.3. FUTURE EXPERIMENTATION: SOME IDEAS

It has been suggested that local response rate patterns may be best understood in terms of the changes in the relative rates of reinforced and other behaviours over time. An approach which shares similar assumptions to those adopted by Herrnstein in generating the equations discussed below may promote such understanding. The emphasis on both reinforced and other behaviour suggests a movement toward a more ethological approach. Traditional operant research has involved little observation. The responses of interest have been those which can be measured by a microswitch and pulseformer without the intervention of the experimenter. However, some recent research has suggested that this is not always the best strategy. Much interesting behaviour is not recorded by the apparatus, but requires observation by the experimenter (e.g. see Staddon and Simmelhag, 1971).

The reason for the lack of observation has clearly been that most experiments have been designed to minimize uncontrolled sources of reinforcement. The range of other behaviour in which an organism can engage in an experimental chamber is relatively small. In addition, deprivation regimens ensure that the magnitude of reinforcement obtained from other behaviour will be only small compared to that delivered according to the schedules. The products of such a strategy were noted by

Herrnstein: "Investigators have made a tacit decision in favour of stability, but at the cost of sensitivity to the independent variable" (Herrnstein, 1970, p.258). By introducing more uncontrolled sources of reinforcement we may be more likely to obtain the type of relations which will help explain local response rate patterns.

Concurrent and multiple schedules arrange more than one source of reinforcement. Changes in the rate of one response resulting from changes in the reinforcement for the other can then be observed. Such experimentation has been successful in yielding the mathematical relations which have been discussed in detail here. But a review of the research resulting from these findings, and the experiments described here, suggest that we also need to be able to more directly measure changes in response rate over relatively short time periods. The type of functional relations which emerges from manipulations of reinforcement rate seems to be critically dependent on these patterns.

Thus, a better understanding should come from experiments in which local response rate patterns are manipulated. From the approach suggested in Chapter 6, this means varying the rate and temporal location of sources of reinforcement other than those explicitly scheduled. Ideally, the amount of reinforcement derived from other behaviour would be measured directly rather than being inferred from a curve-fitting procedure. Whilst this is difficult to achieve, a greater emphasis upon extraneous sources of reinforcement may lead eventually to a better understanding of schedule-controlled behaviour.

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