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Choice behaviour: Short- and long-term effects of reinforcers

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

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ABSTRACT

Behaviour was analysed at a number of levels in two series of concurrent-schedule experiments. In the first, six or seven concurrent-schedule components, each of which could have a different reinforcer ratio in it, were arranged in each session. In the canonical arrangement these components were separated by 10-s blackouts. Across conditions, the reinforcer ratios arranged in components were varied. The overall rate of reinforcement was constant throughout, and each condition was in effect for 50 sessions. The second series of experiments used a conventional switching-key concurrent-schedule procedure in which a single reinforcer (or reinforcer-magnitude) ratio was in effect for 65 sessions.

Experiment 1 showed that behaviour adjusted very quickly to the rapidly changing contingencies. Sensitivity to reinforcement reached higher levels when the range of reinforcer ratios arranged was greater. More detailed analyses suggested that the variables controlling behaviour operated at a number of levels. First, each individual reinforcer had an effect on subsequent behaviour. Second, successive reinforcers obtained at the same alternative ("confirmations") had cumulative effects that were evident when behaviour was examined as a function of time since reinforcement (i.e., the change in behaviour after the third successive confirmation at the left alternative was greater than that after the second). Third, when these sequences of confirmations occurred more frequently, their behavioural effects were again increased. Finally, "disconfirmations" (a reinforcer obtained from the other alternative following a sequence of confirmations) had comparatively very large effects, and returned preference to levels controlled by the molar or sessional reinforcer ratio.
Experiment 2 showed that the local effects of reinforcers evident in
Experiment 1 were also present in steady-state data. Effects of individual reinforcers
on behaviour were evident, as were longer-term effects of aggregations of reinforcers.
Preferences were again more extreme in response to sequences of confirmations when
those sequences occurred more frequently. Similarly, disconfirmations had
comparatively very large effects, and returned behaviour to levels controlled by the
molar reinforcer ratio. Moreover, these local effects of reinforcers were similar when
either the reinforcer-frequency ratio or the reinforcer-magnitude ratios were varied.

The present data question the commonly held assumption that behaviour is
controlled by large aggregations of reinforcers. Control was evident at a number of
levels, and attempts to model concurrent-schedule data are likely to require processes
operating at multiple levels. The present data also suggest that the frequency with
which sequences of confirming reinforcers occurred was central, and longer-term
processes might be updated with the delivery of a disconfirmation. Moreover,
different concurrent-schedule arrangements might result in these frequencies differing
substantially with the same reinforcer ratio arranged. An increased focus on detailed
data collection using relatively standard manipulations of reinforcer frequency,
magnitude, and other independent variables that are known to affect choice, is
recommended.
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Chapter I

Psychologists have researched the distribution of behaviour between response alternatives extensively. As Herrnstein (1970) explained, "even in a simple environment like a single-response operant-conditioning chamber, the occurrence of the response is interwoven with other, albeit unknown, responses, the relative frequencies of which must conform to the same general laws that are at work whenever there are multiple alternatives" (p. 264). That is, all behaviour is choice behaviour. Herein lies the rationale for the extensive focus on choice behaviour and the variables that control it. Concurrent schedules have provided a means by which two (or more) response alternatives can be arranged explicitly, and behaviour emitted at each recorded. Concurrent schedule research has resulted in many predictive and descriptive attempts to model the effects of reinforcement.

1.1 Concurrent-schedule procedures

A concurrent schedule involves two or more response alternatives associated with two or more schedules of reinforcement that are available simultaneously. Two variations of this procedure are commonly used, the two-key procedure and the Findley (1958), or switching-key, procedure. Various response manipulanda can be arranged. For simplicity, generic arrangements designed for pigeons using response keys will be discussed here. Research has shown no differences in performance across the two concurrent-schedule procedures (see Davison & McCarthy, 1988).

The two-key procedure involves two (or more) response keys being made available to the subject simultaneously. Responses on each of these are reinforced according to specific schedules. The subject is free to respond to either key, and
change over at any stage. Responses to each key, and thus its associated schedule, are recorded. When time allocation is measured, the time allocated to a schedule is usually the time between the first response to the key associated with that schedule, and the first response to the other key.

The switching-key procedure also involves two response keys being made available to the subject, the switching key, and the main key. A response to the switching key changes the discriminative stimulus and associated schedule shown on the main key. Thus, all reinforcers are obtained following responses emitted to the main key. Again, the responses to each discriminative stimulus arranged on the main key and its associated schedule are recorded. Time allocation is usually measured from switching-key response to switching-key response.

In both procedures, a changeover delay (COD, Herrnstein, 1961) has often been used. In the two-key procedure, a COD prevents a response on one alternative from producing an arranged reinforcer when it follows a response on the other alternative by less than a specified amount of time. In the switching-key procedure, the COD prevents a main-key response from producing an arranged reinforcer when it follows a switching-key response by less than a specified amount of time. The use of CODs is an attempt to prevent concurrent superstitions, that is, reinforcers obtained at one alternative maintaining responding at the other alternative (Catania, 1963; Catania & Cutts, 1963).

Two different methods of scheduling reinforcers have been commonly used with interval schedules. First, reinforcers can be independently scheduled (e.g., Herrnstein, 1961). This simply means that when a reinforcer is arranged for a response to one alternative of a concurrent schedule, the availability of a reinforcer for the other response(s) is unaffected. Thus, when one schedule arranges a reinforcer,
the other schedule(s) continue timing. It is therefore possible for reinforcers to be arranged simultaneously on more than one of the response alternatives. When a given reinforcer is collected, the schedule involved resumes timing.

In contrast, when reinforcers are dependently scheduled (Stubbs & Pliskoff, 1969), a reinforcer arranged on one alternative stops the other alternative(s) timing until the arranged reinforcer has been collected. Once this has happened, both the schedule on which the reinforcer was arranged and the other schedule(s) resume timing. Dependent scheduling prevents the reinforcement of exclusive responding to one alternative, and ensures that the obtained reinforcer ratio closely approximates the arranged reinforcer ratio.

The last forty years have produced a large number of experimental examinations of concurrent-schedule performance. Davison and McCarthy (1988) provide an extensive review of concurrent schedule research using a variety of schedule combinations. Most research, however, has focused on the use of concurrent variable-interval (VI) VI schedules, as is the case with the present thesis. In a VI schedule a response is reinforced when a variable amount of time has elapsed since the last reinforcer. The schedule is usually denoted by the mean of these intervals.

The great majority of research on concurrent-schedule performance has examined steady-state behaviour. This has usually involved an independent variable (most often the reinforcer ratio) being held constant until a pre-defined stability criterion has been met. Various criteria have been used, with the underlying theme being that there be no systematic variation in behaviour from session to session. This normally requires somewhere between 15 to 30 sessions of training, and the last few sessions of stable data are analysed (Davison & McCarthy, 1988).
1.2 Quantification – The generalized matching law

Herrnstein (1961) reported a two-key concurrent schedule experiment in which responses were reinforced according to a series of different concurrent VI VI schedules, and the overall rate of reinforcement was constant at 1.5 reinforcers per minute. In most conditions he arranged a 1.5-s COD. He noted that the relative frequency of reinforcement equalled the relative frequency of responses on the two alternatives. This matching function is given as:

$$\frac{B_1}{B_1 + B_2} = \frac{R_1}{R_1 + R_2},$$

(1.1)

where $B_1$ and $B_2$ are the numbers of responses emitted at Alternatives 1 and 2 respectively. Similarly, $R_1$ and $R_2$ are the numbers of reinforcers obtained at Alternatives 1 and 2. The number of responses emitted at each alternative can be substituted by the amount of time spent responding at each alternative (Baum & Rachlin, 1969). A number of subsequent studies conformed to this relationship (e.g., Catania, 1963; Reynolds, 1963).

However, Baum (1974) noted several studies where departures from matching were reported, either systematic (Hollard & Davison, 1971; Staddon, 1968; Trevett, Davison, & Williams, 1972) or non-systematic (Baum & Rachlin, 1969; Baum, 1973). For example, Hollard and Davison studied the behaviour of pigeons on concurrent VI VI schedules when food was the reinforcer on one response alternative and ectostriatal brain stimulation (EBS) was the reinforcer on the other. When the logarithms (hereafter logs) of the response ratios were plotted as a function of the logs of the obtained reinforcer ratios a linear relation was evident. However, the slope of the best fitting straight line through these data was not 1.0 as strict matching would require, but less than 1 for each subject (mean 0.77). Baum used the term
"undermatching" to describe this type of result. Moreover, the y-intercepts of these lines was not 0 (as strict matching would require), but consistently positive (mean 0.65), indicating a strong preference for food over EBS. Baum termed this type of deviation from strict matching “bias”.

Baum (1974) suggested that a modified version of the matching law, the generalized matching law (GML), could better describe the majority of concurrent schedule research. The GML, in its logarithmic form, is given by:

$$\log \left( \frac{B_1}{B_2} \right) = a \log \left( \frac{R_1}{R_2} \right) + \log c,$$

where the parameter $a$ is sensitivity to reinforcement (Lobb & Davison, 1975) and measures the degree to which the response ratio changes with variations in the reinforcer ratio. Log $c$ is inherent bias, and measures any constant proportional preference for one alternative over the other. As with Equation 1.1, time allocation can be substituted for response allocation. In arithmetic terms, the GML is given by:

$$\frac{B_1}{B_2} = c \left( \frac{R_1}{R_2} \right)^a,$$

Strict matching demands that the value of sensitivity to reinforcement be 1.0. That is, the behaviour ratio must have unit sensitivity to the reinforcer ratio when the latter is varied. Undermatching describes the result where the behaviour ratio has less than unit sensitivity ($a < 1.0$) to the reinforcer ratio. That is, the behaviour ratio is consistently less extreme than the reinforcer ratio that produced it. Overmatching ($a > 1.0$) is a somewhat less frequent result (Taylor & Davison, 1983), in which the behaviour ratio has a greater than unit sensitivity to the reinforcer ratio.

In concurrent schedules, sensitivity to reinforcement is typically less than 1.0 (Baum, 1979; Taylor & Davison, 1983) for both time and response allocation. In
general, time allocation measures of sensitivity to reinforcement are slightly higher than those obtained using response allocation data. Thus, undermatching is the standard result when concurrent VI VI schedules have been used.

Baum (1974) retained the theoretical position that strict matching was the empirical standard, and that deviations from that were most likely due to procedural factors. His argument centred on the notion that scientific research would involve factors that reduce the amount of systematic variation in data. Thus, observed values of a dependent variable would co-vary less with an independent variable than would be predicted, and in matching this would lead to undermatching. He outlined three factors: CODs, deprivation, and poor discrimination between alternatives. Other researchers have identified other factors that affect sensitivity to reinforcement to varying degrees. Among others, these include: Asymmetrical pausing at the two alternatives, overall rate of reinforcement, and amount of training.

1.2.1 Changeover delays

Baum (1974) suggested that in the absence of a COD, or when CODs were too short, preference tended to undermatch reinforcer ratios. He argued this point largely on the basis of data reported by Shull and Pliskoff (1967). They arranged concurrent VI 60-s VI 180-s schedules with the COD increasing from 0 to 20 s and then decreasing to 0 s again. As the COD was increased, sensitivity to reinforcement also increased. However, when the COD was decreased there was no corresponding decrease in sensitivity to reinforcement (see Davison & McCarthy, 1988). Baum’s argument would suggest that sensitivity should also decrease as a COD is decreased. More recently, Temple, Scown, and Foster (1995) reported little change in sensitivity to reinforcement with CODs of 2, 4, 7.5, and 15 s.
1.2.2 Deprivation

Baum (1974) also suggested deprivation level affects the value of sensitivity to reinforcement. He cited multiple VI VI schedule research reported by Herrnstein and Loveland (1974), which showed that sensitivity to reinforcement increased as deprivation levels were increased. However, subsequent research (McSweeney, 1975) showed that deprivation does not affect concurrent VI VI schedule performance.

1.2.3 Poor discrimination between alternatives

Baum (1974) argued that poor discrimination between the two alternatives (i.e., left key versus right key in a two-key procedure, or the two colours of a switching-key procedure) of concurrent schedules might produce undermatching. His argument was made on the basis of a suggestion by Lander and Irwin (1968) that sensitivity to reinforcement be allowed to be less than 1.0 to account for behavioural contrast in multiple schedules. Miller, Saunders, and Bourland (1980) reported research that could be interpreted as supporting Baum’s position. They signalled the two alternatives of a switching-key concurrent schedule with line orientations and reported that sensitivity to reinforcement dropped as the line orientations became more similar. An alternative interpretation of this result is presented below. In more standard arrangements, Charman and Davison (1983) showed that pigeons could perfectly discriminate red and green keylight stimuli, even in multiple VI VI schedules where the discrimination would be expected to be more difficult. Moreover, as Davison and McCarthy (1988) point out, behavioural detection research has shown that left versus right keys are also highly discriminable to pigeons.
It remains that another failure of discrimination is also possible. A sensitivity to reinforcement value of 1.0 requires that a subject perfectly discriminate the reinforcer rates available from the two alternatives. Davison and McCarthy (1988) point out that this seems unlikely, although at the time it had not been directly assessed (see also Davison, 1990; Wearden, 1980).

1.2.4 Asymmetrical pausing

Baum (1979) argued that a tendency to pause longer after responses at one of the alternatives affects time-allocation measures of sensitivity to reinforcement (time allocation is generally measured from changeover to changeover, see also Taylor & Davison, 1983). Clearly, asymmetrical pausing adds time to the alternative favoured for pausing. If this alternative is a particular response key or stimulus, a bias results. If, however, the alternative favoured is that providing the higher or lower rate of reinforcement time allocation estimates would be affected. Specifically, if more pausing occurs at the higher reinforcer-rate, time allocation would be overestimated, and sensitivity to reinforcement would increase. In contrast, more pausing at the lower reinforcer-rate alternative would result in time allocation being underestimated, and sensitivity to reinforcement decreasing.

Baum (1979) argued that the latter was more frequently the case, although no empirical evidence was provided. One obvious problem with this position is that time allocation measures of sensitivity to reinforcement are typically higher than those obtained from response allocation (Taylor & Davison, 1983). Additionally, Baum and Rachlin (1969) had earlier argued for time allocation as the more fundamental measure of behaviour (but see Davison, 1991). However, Aldiss and Davison (1985) showed that when a time allocation measure is used that is relatively uncontaminated
by time spent emitting behaviours other than key pecking, time allocation measures of
sensitivity to reinforcement were lowered to levels similar to response allocation
measures of sensitivity to reinforcement.

1.2.5 Overall rate of reinforcement

Alsop and Elliffe (1988) systematically investigated the effects of overall rate
of reinforcement on arithmetic concurrent VI VI schedule performance. They
arranged 31 conditions, consisting of six sets of conditions where the overall rate of
reinforcement was constant and the ratio of reinforcers varied from 1:8 to 8:1. Across
the sets of conditions the overall rate of reinforcement was varied from 0.22 to 10
reinforcers per minute. Performance was described well by the GML. However,
Alsop and Elliffe showed clearly that sensitivity to reinforcement increased with
overall reinforcer rate. Elliffe and Alsop (1996) later replicated this study using
exponential, rather than arithmetic, concurrent VI VI schedules. They found that
sensitivity to reinforcement changed non-monotonically as a function of the overall
rate of reinforcement. As overall reinforcer rate was increased, sensitivity to
reinforcement increased to a maximum at 2 arranged reinforcers per minute, and
decreased thereafter. Thus, the relationship between overall rate of reinforcement and
sensitivity to reinforcement is dependent on the type of schedules used. However, the
reasons for the differences are not yet clear.

1.2.6 Amount of training

Todorov, Castro, Hanna, Bittencourt de Sa, and Barreto (1983) exposed
pigeons to concurrent VI VI schedules in nine experimental conditions. They fitted
the GML after the first five, six, seven, eight, and nine conditions, respectively. They
found that sensitivity to reinforcement, for both response- and time-allocation measures, tended to decrease with the number of experimental conditions, and increase with the number of sessions per condition. They also reviewed the concurrent-schedule literature and confirmed these general effects.

Davison and Jones (1995) arranged a series of concurrent schedule conditions in which the reinforcer ratios of up to 160:1 were arranged. Their results are discussed in the context of the contingency-discriminability model (Davison & Jenkins, 1985) below. No significant trends were evident in values of sensitivity to reinforcement as a function of increasing number of conditions. However, when the GML was fitted to their central data only (data where the log reinforcer ratio was between −1 and 1), sensitivity to reinforcement increased for each individual subject when compared to sensitivity to reinforcement when all data were used. Therefore, Davison and Jones suggested that Todorov et al.’s result was not in fact due to an increasing number of experimental conditions, but due to the fact that the most extreme reinforcer ratio conditions were arranged later in training by Todorov et al.

1.2.7 Summary

The GML describes well the vast majority of concurrent VI VI schedule research where relative frequency of reinforcement has been varied. However, if the model is to be considered predictive, it can be only in the sense that behaviour allocation should be controlled by the relative rates of reinforcement. The finding that overall reinforcer rates affect sensitivity to reinforcement (Alsop & Elliffe, 1988; Elliffe & Alsop, 1996) clearly violates this prediction. The GML provides no mechanism via which the observed regularities, specifically undermatching, can be achieved. Moreover, the research discussed above has, in general, failed to support
Baum’s position that strict matching is the norm. Thus, the GML is best considered a
descriptive tool (Alsop & Elliffe, 1988).

1.3 Quantification – The contingency discriminability model

Davison and Jenkins (1985) offered a second quantitative model of concurrent-schedule performance (see also Vaughan & Herrnstein, 1987). Miller et al. (1980) used a switching-key concurrent-schedule procedure in which the alternatives were signalled by different line orientations on the main key. They used three groups of pigeons. Across groups the orientations of the lines signalling the alternatives on the main key differed by 0, 15, or 45 degrees. They showed that sensitivity to reinforcement increased as the physical disparity between the stimuli signalling the alternatives increased. On the basis of this result, Davison and Jenkins proposed the contingency-discriminability model. This model assumes that changing the physical disparity between discriminative stimuli affects how well animals can accurately discriminate between the different response–reinforcer contingencies. The contingency-discriminability model is given by:

\[
\frac{B_1}{B_2} = c \left( \frac{d_r R_1 + R_2}{d_r R_2 + R_1} \right),
\]

(1.4)

where \(d_r\) is a measure of contingency discriminability, the discriminability between response-reinforcer relations. The value of \(d_r\) can vary between 1, which indicates no discrimination, and infinity, which indicates perfect discrimination. It can be seen that when \(d_r\) is infinite, the model predicts strict matching. Davison and Jenkins showed that the model described Miller et al.’s data well, and yielded interpretable measures of contingency discriminability.
The contingency-discriminability model has one important advantage over the GML: It provides a mechanism via which the commonly found result — undermatching — can be predicted. However, it also has one limitation; when discriminability is infinite, the model predicts strict matching biased by the value of $c$. Thus, the model cannot predict overmatching. Nonetheless, it remains that in standard concurrent VI VI schedules the two models describe the data equally well, as overmatching is a rare finding (Baum, 1979; Taylor & Davison, 1983). Differences between the two models only become apparent when relatively extreme reinforcer ratios are arranged. This is because the contingency-discriminability model suggests that the relation between log response ratios and log reinforcer ratios is ogival, rather than linear as suggested by the GML. Specifically, at extreme log reinforcer ratios the contingency-discriminability model suggests that log response ratios will be less extreme than does the GML.

Davison and Jones (1995) examined this prediction using a switching-key concurrent-schedule procedure in which the two alternatives were signalled by different intensities of light. Reinforcer ratios of up to 160:1 were arranged. They showed that the contingency-discriminability model fitted their data marginally better than the GML. However, Baum, Schwendiman, and Bell (1999) reported a similar experiment using a two-key concurrent-schedule procedure. They suggested that Davison and Jones’ results might have been found in part because of the unusually confusable stimuli used. Baum et al. showed that their data were described marginally better by the GML.

It remains that both models describe the majority of concurrent-schedule data well. However, one further point of difference between the two models concerns behaviour when the reinforcer rate on one alternative is extinction. The GML, quite
clearly, predicts exclusive responding. However, assuming $R_2$ is zero, the contingency-discriminability model becomes:

$$\frac{B_1}{B_2} = c \left( \frac{d_2 R_1}{R} \right) = c d_r,$$

(1.5)

Thus, as long as $d_r$ is not infinite, the contingency-discriminability model predicts the maintenance of responding on the alternative associated with extinction. Furthermore, this responding would be independent of the reinforcer rate on the alternative being reinforced. Davison and Jones (1998) arranged five conditions in which one or the other alternative of a concurrent schedule was always extinction, and the reinforcer rate on the second alternative was varied. They confirmed both predictions: Responding was never consistently exclusive; and the log response ratio emitted was consistent irrespective of the reinforcer rate on the reinforced alternative.

1.3.1. Summary

The contingency-discriminability model, like the GML, describes well the vast majority of concurrent-schedule research in which the relative frequency of reinforcement has been varied. The model has a major advantage in that it proposes a conceptually clear mechanism to predict undermatching. However, the relatively rare finding of overmatching cannot be predicted. The research is not clear on whether the contingency-discriminability model describes concurrent-schedule performance better than the GML. At extreme reinforcer ratios the ogival function predicted by the contingency-discriminability model was confirmed in one study (Davison & Jones, 1995) using a slightly unusual stimulus arrangement, and not by another (Baum et al., 1999) using more conventional stimuli. Whereas the maintenance of responding under extinction predicted by the contingency-discriminability model, and not by the GML, was confirmed by Davison and Jones (1998).
1.4. \textit{Overall Summary}

Steady-state concurrent-schedule performance has been quantified successfully using both the GML and the contingency-discriminability model. The former provides an excellent descriptive tool, while the latter also describes concurrent VI VI schedule performance well while providing a conceptually clear mechanism through which the standard results can be predicted. It remains, however, that research has not yet been unequivocal in supporting either model.

The GML has undoubtedly been the more influential model in terms of how concurrent-schedule performance has been viewed, and is stated at a molar level — a level at which responses and reinforcers are aggregated over large periods of time without regard for any lower level regularity. Thus, the GML implies that behaviour is controlled by large aggregations of reinforcers. Indeed, this is the level at which regularity has been observed, and the GML is a statement of the quantitative relations observed at this level of analysis. As Dreyfus (1991) noted, this implicit assumption about the level at which the variables controlling concurrent-schedule performance operate has been reflected in the manner in which data are collected and analysed.
Chapter II

As outlined in Chapter 1, steady-state concurrent-schedule performance has been the focus of a great deal of research. The GML (Equations 1.2 and 1.3, Baum, 1974) has been used successfully to quantify the relationship between the logs of the behaviour ratios and the logs of the reinforcer ratios obtained using concurrent VI VI schedules. This relationship is generally accepted as being a linear one (but see Davison & Jenkins, 1985; Davison & Jones, 1995). With steady-state behaviour quantified in this way, some researchers began to investigate aspects of environmental variability that might affect the acquisition and distribution of behaviour in concurrent schedules.

2.1 Between-session changes in reinforcer ratios

Davison and Hunter (1979) examined the control exerted over current preference by the reinforcer ratios in effect in previous sessions. They trained pigeons on concurrent VI VI schedules in which the reinforcer ratio was progressively increased across seven conditions (from Ext:VI 60-s to VI 60-s:Ext) and then decreased again. They also arranged a set of conditions in which the reinforcer ratios were varied in an irregular order. Each reinforcer ratio was in effect for six sessions. Davison and Hunter analysed performance in terms of the GML in the first, third, and sixth sessions following a change in the reinforcer ratio. They showed that the previous reinforcer ratio had a large effect on preference in the first session following a change. There remained a measurable effect three sessions after a change, but this effect had disappeared six sessions after a change. Sensitivity to the current reinforcer ratio reached close to its asymptotic level (about 0.80) after about six sessions.
following a change in the reinforcer ratio. Thus, Davison and Hunter were able to demonstrate that orderly and quantifiable changes in behaviour occurred during transitions between steady states.

Hunter and Davison (1985) arranged two experimental conditions, a concurrent VI 60-s VI 240-s schedule and a concurrent VI 240-s VI 60-s schedule. Which of these two arrangements was in effect in each session was determined by a single 31-step pseudorandom binary sequence, and this sequence was repeated during the study. A pseudorandom binary sequence has no sequential dependencies, and thus cannot be predicted by the subject. Hunter and Davison used systems theory to identify the relation between log response ratios in the current session and log reinforcer ratios in previous sessions. The session-to-session response ratios resulting from the pseudorandom variations in reinforcer ratios each session were well predicted by impulse-response functions that Hunter and Davison identified for each subject. A second-order dynamic model containing two parameters was fitted, and the results implied that the effects of a change in log reinforcer ratios should be almost complete within five sessions.

Davison and McCarthy (1988) presented an alternative analysis of Hunter and Davison’s (1985) data in terms of the GML. They used linear regressions to fit the current session’s log response ratios against the current session’s log obtained reinforcer ratio, giving a value of sensitivity to reinforcement at Lag 0. Residuals were then calculated and regressed against the previous session’s (Lag 1) log obtained reinforcer ratio. This was repeated up to Lag 10. Values of sensitivity to reinforcement were significantly positive up to Lag 3. This result is consistent with that reported by Davison and Hunter (1979), specifically that performance three sessions following a change in the reinforcer ratio was still affected by the previous
reinforcer ratio. Davison and McCarthy noted that the sum of the mean sensitivity to reinforcement values up to Lag 3 was 0.62. When the lag was increased to 10, this value increased to 0.70. Thus, Davison and McCarthy suggested that even longer lasting effects of previous conditions than those shown by Davison and Hunter (1979) might be present.

Schofield and Davison (1997) replicated and extended Hunter and Davison’s (1985) research. They used the same 31-step pseudorandom binary sequence, and varied the size of the reinforcer ratios available on the concurrent schedules. Across three conditions the reinforcer ratios arranged were, 4:1 and 1:4, 8:1 and 1:8, and 2:1 and 1:2. Schofield and Davison found no evidence that the size of the reinforcer ratios affected either sensitivity to reinforcement, either overall or in the current session. However, they did find that after a number of exposures to the pseudorandom binary sequence, control by the previous session’s reinforcer ratios (lag greater than 0) was not evident. Control had become localised to the extent that only the current session’s reinforcer ratio was affecting preference.

2.2 Single within-session changes in reinforcer ratios

Mazur and his colleagues (Bailey & Mazur, 1990; Mazur, 1992; 1995; 1996; 1997; Mazur & Ratti, 1991) have reported a series of experiments examining the development of preference for one alternative over another in various choice situations. Their generic procedure consists of several sessions of training with a particular reinforcer ratio prior to a transition session, during which at an unpredictable time a single step change in the reinforcer ratio occurs, and finally, approximately four post-transition sessions.
Bailey and Mazur (1990) and Mazur and Ratti (1991) used variable ratio (VR) schedules to measure the acquisition of preference for an alternative providing a higher rate of reinforcement in discrete-trials and free-operant procedures respectively. Both studies documented large-scale changes in preference within a single session. Moreover, both studies showed that asymptotic preference for the higher reinforcer-rate alternative was reached more quickly when the ratio of the reinforcement probabilities was larger. Mazur and Ratti, for example, arranged schedules with a .06 difference in the probability of reinforcement, but found asymptotic preference was reached more quickly when the ratios were .07 and .01, than when they were .16 and .10.

In his Experiment 2, Mazur (1992) investigated the development of a preference for one alternative over the other using VI schedules. He used the generic procedure described above, and each condition began with equal concurrent VI VI schedules. During the transition session, the proportion of reinforcers arranged on one of the alternatives changed to .60, .75, or .90. Mazur showed that the rate of approach to asymptotic preference was similar across all conditions, and like Schofield and Davison (1997) concluded that the size of a change in reinforcer ratios did not affect rate of behavioural adjustment.

Mazur (1995) used a variation of the same procedure. However, prior to the transition session the concurrent VI VI schedules were unequal – the proportion of reinforcers assigned to one key was .10, .25, or .40, and during the transition session these changed to .90, .75 and .60, respectively. Mazur documented large changes in preference in the transition session. When the proportion of responses emitted on the richer of the two alternatives was examined, the largest effect seemed to occur when the change in reinforcer proportions was largest (i.e., .10 to .90). However, Mazur
also examined the transition data as a percentage of asymptotic performance. When this was done, the approach to asymptotic preference was slightly, but significantly, faster when the change in reinforcement proportions was smaller.

Mazur (1995) also reported what he termed a "spontaneous recovery" effect. He found that, in sessions following a transition, response proportions reverted towards the pre-transition levels. This effect was evident across all conditions, and increased with an increasing change in reinforcer proportions. This replicated, and extended to a different procedure, the finding that reinforcers obtained in previous sessions affected performance in the current session (Davison & Hunter, 1979; Hunter & Davison, 1985; Schofield & Davison, 1997).

In another similar experiment, Mazur (1996) replicated and extended the spontaneous recovery finding. He showed that it often occurred in the second and third session following a transition, analogous to findings by Davison and Hunter (1979) and Hunter and Davison (1985) that control by a previous reinforcer ratio was still evident three or four sessions following a change. Mazur also showed that the spontaneous recovery was not simply a regression towards indifference; both more and less extreme preferences were observed after a transition depending on the reinforcer proportion in effect prior to the transition. Finally, Mazur included some conditions where a "rest period" of three days was included prior to a transition session. Less spontaneous recovery was evident when a rest period was included, suggesting that the influence of prior sessions on current performance diminished with the passage of time.

Mazur (1997) investigated the effects of both the rate of reinforcement and the frequency of environmental change on behaviour. He used a variation of the procedure described above. Conditions began with a baseline phase of variable length
during which the concurrent VI VI schedules were equal. A transition phase, three sessions in length, followed in which the percentage of reinforcement for one key was higher (70% or 90%) than for the other. The rate of reinforcement was also varied across three levels (single overall VI 15-s, VI 60-s, or VI 180-s). Each of the six possible combinations of the two independent variables was repeated four times in a counterbalanced order. The spontaneous recovery finding was replicated, and behaviour adjusted more quickly to a change in the reinforcement percentages when the reinforcer rate was higher.

In his Experiment 2, Mazur (1997) varied the frequency of environmental change. Reinforcement percentages were changed about every eight sessions in Phases 1 and 3, and every one or two sessions in Phase 2. The size of the change in the reinforcement percentages was varied across conditions. In all cases Mazur found that acquisition was more rapid when the reinforcement contingencies changed more quickly (Phase 2). In discussing the results from his two experiments, Mazur concluded “the delivery of an individual reinforcer can change a subject’s choice responses to a greater or lesser extent, depending on the overall context in which the reinforcer occurs” (p. 125).

2.3 *Multiple within-session changes in reinforcer ratios*

Dreyfus (1991) investigated the effects on time allocation of local changes in the reinforcer rates arranged on concurrent schedules. He arranged concurrent schedules that featured regular unsignaled changes in relative rates of reinforcement. Across conditions he varied the number and frequency of these shifts, and the overall rate of reinforcement. Specifically, in his Experiment 1, Dreyfus arranged components either 10 or 30 min in duration, and sessions either two or four
components in duration. In Experiment 2, Dreyfus arranged four components per session either 10 or 30 min in duration, and the overall rate of reinforcement was varied over three levels. Relative time allocation followed changes in relative reinforcer rates more closely when components were longer, and when the overall rate of reinforcement was higher. The latter is consistent with the steady-state finding that sensitivity to reinforcement changed with overall rate of reinforcement (Alsop & Elliffe, 1988; Elliffe & Alsop, 1996).

Dreyfus' (1991) finding that behaviour came under the control of local changes in relative reinforcer rates was clouded by the fact that these changes occurred at regular times within sessions. It was, therefore, possible that behaviour had come under the control of elapsed session time. This is countered somewhat by the effect of overall rate of reinforcement. Moreover, as Dreyfus suggested, the most likely way for behaviour to come under the control of elapsed session time was through sensitivity to the local changes in reinforcer rates.

Belke and Heyman (1994) introduced a procedure in which subjects were exposed to seven different reinforcer ratios in a single session. They were examining the effects of extraneous reinforcers and Herrnstein's (1970) equation. The procedure, however, provides a means of examining preference under conditions that change very rapidly. Davison and Baum (2000) used this procedure to examine the effects of frequency of environmental change and overall reinforcer rate on choice behaviour.

Davison and Baum (2000) used a two-key concurrent-schedule procedure. Sessions consisted of seven components, each with a different reinforcer ratio (27:1, 9:1, 3:1, 1:1, 1:3, 1:9, or 1:27) separated by 10-s blackouts. The reinforcer ratios were arranged in a random order in each session, and each occurred only once in a session.
Each condition lasted 50 sessions, and data from the last 35 sessions were analysed. In their Part 1, the overall rate of reinforcement was held constant, and the frequency of environmental change manipulated by varying component length from four to twelve reinforcers. In Part 2, the overall rate of reinforcement was varied with components either four or twelve reinforcers in length.

Davison and Baum (2000) examined their data at a number of levels and reported several interesting results. Behaviour adjusted rapidly within components as successive reinforcers were obtained. Davison and Baum calculated a value of sensitivity to reinforcement at each successive reinforcer delivery within a component, and found that these reached moderate levels (0.5 to 0.6) after about seven or eight reinforcer deliveries. Control by the previous-component reinforcer ratio carried over into the present component, and was evident even after five or six reinforcer deliveries in the present component. No effect of component length was evident on behaviour. However, behavioural adjustment was faster, and sensitivity to reinforcement reached higher levels when the overall rate of reinforcement was higher. The latter result replicated that of Dreyfus (1991) in a less predictable environment, and again is consistent with steady-state findings (Alsop & Elliffe, 1988: Elliffe & Alsop, 1996).

At a more local, reinforcer-by-reinforcer, level, Davison and Baum (2000) showed that individual reinforcers had striking regular effects on behaviour. They examined specific sequences of reinforcers obtained within components and showed that reinforcers obtained from the same alternative as the previous reinforcer (confirming reinforcer) had diminishing effects on behaviour. In contrast, a reinforcer obtained from the opposite alternative to the previous reinforcer (disconfirming reinforcer/disconfirmation) had comparatively very large effects on preference.
Davison and Baum proposed a local accumulator-based model to account for their results. This model will be discussed below.

Davison and Baum (2002) used the Belke and Heyman (1994) procedure to investigate the effects of varying the blackout duration between components, and arranging periods of unsignaled extinction instead of blackouts between components. They noted that in the Davison and Baum (2000) study, the 10-s blackouts between components, despite being highly discriminable events, failed to eliminate the effects of reinforcers obtained in the previous component. In their first experiment they varied the duration of the blackout between components from 1 s to 120 s. Components were either four or ten reinforcers in length. Davison and Baum showed that the amount of carryover from, or control exerted by, the previous-component reinforcer ratio decreased as the blackout duration increased. This result parallels that reported by Mazur (1996), that the passage of time influenced control exerted by a previous reinforcer ratio. They also showed that each reinforcer produced a large immediate shift in preference, but that preference decreased during inter-reinforcer intervals (IRIs). They speculated that the preference change evident between components might follow the same function as the preference change between reinforcers.

To investigate this more closely, Davison and Baum (2002) arranged a further four conditions. Components were either four or ten reinforcers in length. In two conditions they arranged 60-s blackouts between components, and in the other two 60-s periods of unsignaled extinction were arranged instead of blackouts. Preference during the extinction period fell towards indifference. Moreover, the preference emitted following extinction periods was much the same as that emitted following blackouts between components. Davison and Baum always arranged the same
symmetrical distribution of reinforcer ratios (i.e., 1:27 to 27:1). Thus, they were unable to distinguish whether this movement of preference during the unsignaled extinction was really a movement towards indifference, or a movement towards, or controlled by, the molar reinforcer ratio (1:1). Mazur's (1996) report that the spontaneous recovery effects he observed were evident towards both more and less extreme reinforcer ratios suggests that perhaps the latter could have been the case. It remains, however, that Mazur's and Davison and Baum's procedures were very different, and some caution must be exercised when comparisons are drawn between them.

2.4 Local models of performance

As outlined in Chapter 1, the greatest successes at quantifying the effects of reinforcers on behaviour have been realised at molar levels of analyses (Baum, 1979; Davison & Jenkins, 1985; Davison & McCarthy, 1988; Wearden & Burgess, 1982). The matching relation is compatible with numerous dynamic choice processes, and thus numerous possibilities have been suggested. The purpose of the present thesis is not to present an exhaustive summary and review of the numerous more local models of choice behaviour. In light of the research discussed above some of the models derived from, or relevant to, this research will be discussed. Particularly in changing environments, the time frame over which reinforcers are integrated to control current behaviour, and the variables that affect this integration, are of both empirical and theoretical importance.

In a discussion of foraging behaviour in changing environments, Dow and Lea (1987) suggested that a forager's estimates of reinforcer frequency must be a function of their past history. Moreover, these estimates must be changeable, but not too
changeable, in response to local changes in reinforcer frequency. That is, even in high reinforcer frequency conditions there will be occasional periods of non-reinforcement. A drastic change in reinforcer estimates, and thus behaviour, under such conditions would be inappropriate. Similarly, the opposite scenario would apply in a low reinforcer frequency environment. Any model that integrates past events must, in some way, make a compromise between these two requirements.

Dow and Lea (1987) suggest one way of effecting such a compromise is by means of a simple “memory window”. In its simplest form, this means an animal remembers perfectly all events during the last \( x \) time units, and totally forgets any events prior to this time (also termed a moving average, Killeen, 1981). A second approach is exemplified by the exponentially weighted moving average model (EWMA, Killeen, 1981). Using this approach, a forager’s estimate of reinforcer frequency is based on both current and previous events. A weighting of \( b \) is given to previous events, and a weighting of \( 1-b \) is given to current events. Dow and Lea termed such models as the variations of the “common model”. They also noted that there remain many ambiguities regarding how the estimates of reinforcer frequency produced by these models should be arrived at. Nonetheless, a general hypothesis remains: In a stable environment, a wide memory window (large \( x \)) or heavy weighting to previous events (high \( b \)) should be used, and in frequently changing conditions a narrow memory window (small \( x \)) or heavy weighting to current events (low \( b \)) should be used.

Principally to test this basic hypothesis, Dow and Lea (1987) arranged a switching-key concurrent-schedule procedure in which the schedule types changed unpredictably from session to session. In their Experiment 1, they varied both the probability of reinforcement and the structure of the schedule associated with each
alternative. Reinforcers could be delivered with a fixed probability per response, or a decreasing probability with each successive reinforcer (depleting patch). Following a changeover, the probability of reinforcement at the alternatives could remain at its depleted levels, or be returned to its original level. In Experiment 2, they held the probability of reinforcement at one alternative constant for a fixed number of reinforcers, after which it immediately fell to zero. The probability of reinforcement at the second alternative depleted with successive reinforcer deliveries. Dow and Lea concluded that their results supported the general hypothesis stated above. Perhaps the most crucial finding concerned behaviour in refreshing patches. Such conditions require that previous estimates of reinforcer frequency be disregarded, thus implying a low weighting to previous events (high $b$). Dow and Lea reported that changeover responses were less frequent in refreshing patches than in non-refreshing patches, implying that previous events were being disregarded more in those conditions. Thus, support was provided for the notion that an animal's memory window might vary in response to environmental contingencies. This notion is also consistent with the research discussed above which suggested that control over responding became more local in nature as environments changed more quickly (Davison & Baum, 2000; Davison & Hunter, 1979; Hunter & Davison, 1985; Schofield & Davison, 1997).

Davis, Staddon, Machado, and Palmer (1993) took a slightly different approach with their development of the cumulative-effects model. The model is non-local in nature – that is, information from the beginning of an animal's experience in a given situation is retained. It also incorporates a winner-take-all response rule; that is, the behaviour with the highest strength will be the one emitted. Davis et al. also incorporated diminishing returns of both response and reinforcers into their model. Diminishing returns with respect to behaviour is a general principle of learning,
however Davis et al. suggested that diminishing returns with respect to reinforcers were at least as important. The notion here is that the more reinforcers that have been obtained in a given context, the smaller the effect of each one.

Davis et al. (1993) incorporated these ideas into the cumulative-effects model based on a response-by-response process as follows. Each choice is represented by a strength variable \( V_i \). Simply, the response with the highest \( V \) value will be the one to occur. \( V \) values are relative reinforcer frequencies in which the reinforcer numerator and response denominator are cumulated from the beginning of the experiment. The cumulative-effects model can be written for each alternative as:

\[
V_i(t + 1) = \left( \frac{R_i(t) + R_i(0)}{B_i(t) + B_i(0)} \right), \quad B_i(0) \geq R_i(0) > 0 \quad (2.1)
\]

where \( R_i(t) \) is the number of reinforcers for response \( i \) from the beginning of the experiment until iteration \( t \). Similarly, \( B_i(t) \) is the number of times the response \( i \) has occurred. \( R_i(0) \) and \( B_i(0) \) are constants that represent initial conditions, a number of responses and reinforcers representing the cumulative effects of an animal’s previous experience.

Davis et al. (1993) showed that the cumulative-effects model accounted better for several features of experimental data than did two versions (on local and one non-local) of the common model. They suggest that the cumulative-effects model has a greater applicability than any other operant behaviour model of which they were aware. They do, however, note, some limitations. These included: As a deterministic model, it makes some wrong predictions at a molecular level; the absence of a discrimination threshold – i.e., the highest \( V \) wins irrespective of the magnitude of the differences; and, that the values of \( R \) and \( B \) can rise without any limit. They argued that many of these could be remedied with ad-hoc alterations to
the model, but such changes would add nothing to the understanding of basic learning processes, thus the limitations were better to be acknowledged until a greater understanding of the deterministic process was attained.

Mazur and colleagues (Bailey & Mazur, 1990; Mazur, 1992; Mazur & Ratti, 1991) showed that a variety of models including Myerson’s kinetic model (Myerson & Hale, 1988; Myerson & Miezin, 1980), Staddon’s ratio invariance model (Staddon, 1988; Staddon & Horner, 1989), and the linear operator model (Bush & Mosteller, 1955 – a precursor to the common model) could not account for their results. However, Mazur showed that a simple mathematical model could. This model states that each response alternative \((i)\) has a separate strength \((V_i)\). This response strength increases each time the response is reinforced, and decreases each time the response is not reinforced. \(V_i\) could vary from 0 to 1, and would increase each time a response is reinforced as follows:

\[
\Delta V_i = r(1 - V_i),
\]

where \(\Delta V_i\) is the change in strength of \(V_i\), and \(r\) is a reinforcement parameter that can change from 0 to 1. After each non-reinforced response, response strength decreases as follows:

\[
\Delta V_i = n(- V_i),
\]

where \(n\) is a non-reinforcement parameter that can range from 0 to 1.

Unlike the cumulative-effects model that uses a winner-take-all response rule, Mazur’s (1992) model incorporated a matching rule to translate the independent response strengths into the probability that one will occur:

\[
p_i = \frac{V_i}{V_1 + V_2},
\]
This model did a reasonable job of predicting performance given basic manipulations in Mazur's generic procedure. However, the model, and indeed the cumulative-effects model, could not predict the spontaneous recovery effects that Mazur (1995; 1996) later showed. The reason for this is simple - these models do not treat the beginning of a session, or more generally the passage of time, in any special way. It is merely assumed that behaviour at the start of a new session (i.e., after a considerable delay) will resume where it left off at the end of the previous session. Mazur (1995) reasoned that this was an untenable position, and that behaviour at the start of a new session should be a result of a weighted average of the events of previous sessions. Thus, Mazur ran a series of computer simulations based on Equations 2.2 to 2.4. However, at the start of a session he set the values of $V_1$ and $V_2$ not at their values from the end of the prior session, but at a weighted average of their values from the previous five sessions (the most recent session received the greatest weight). Given this manipulation, the magnitude and time course of the spontaneous recoveries evident in the actual data were closely approximated by the computer simulations.

Mazur (1997) reported that the rate at which behaviour adapted to a change in reinforcement contingencies varied with the overall rate of reinforcement. These changes in the rate of transition were smaller than the changes in the overall rate of reinforcement, which again was problematic for models such as the kinetic model (Myerson & Hale, 1988; Myerson & Miezin, 1980) which, although predicting an effect of rate of reinforcement, predicts that rate of transition would be strictly proportional to the overall rate of reinforcement. However, this result was also inconsistent with the approach taken in Equations 2.2 to 2.4, which predicts little or no effect of rate of reinforcement on the rate of transition.
A final model to be considered here was proposed by Davison and Baum (2000). Their model is a local one considering behaviour change as a function of reinforcement and non-reinforcement based on the contingency-discriminability model proposed by Davison and Jenkins (1985, Equation 1.4). In that model, the discriminability of response-reinforcer relations ($d_r$) determines the effects of obtained reinforcers on behaviour. Davison and Baum’s model is also closely related to the cumulative-effects model (Davis et al., 1993) as the effects of reinforcers at each alternative are accumulated, via the response-reinforcer discrimination process. The passage of time itself is suggested both to decrease the accumulations, and to mix the reinforcer accumulations to the two alternatives.

The Davison and Baum (2000) model proposes three processes. In the first, reinforcers are allocated to the two response-related accumulations according to Equations 2.5 and 2.6. For the $i$th reinforcer delivery, at either alternative ($R_{l,i}$ or $R_{r,i}$):

$$R'_{l,i} = R'_{l,i-1} + p_d R_{l,i} + (1 - p_d) R_{r,i},$$  \hspace{1cm} (2.5)

and

$$R'_{r,i} = R'_{r,i-1} + p_d R_{r,i} + (1 - p_d) R_{l,i},$$  \hspace{1cm} (2.6)

where either $R_{l,i} = 1$ and $R_{r,i} = 0$, or vice versa dependent on the alternative at which the reinforcer was obtained. $R'$ is the reinforcer accumulation prior to (subscript $i - 1$) and after (subscript $i$) reinforcer $i$. The contingency (response-reinforcer) discriminability parameter ($p_d$) determines the probability with which the just-obtained reinforcer will be allocated to the just-emitted response or to the alternative response, and can vary from .5 (indiscriminable contingencies) to 1 (perfectly discriminable contingencies). If, when a reinforcer is obtained, $p_d$ equals 1, then the reinforcer will always be allocated to the response that it followed. If, however, $p_d$ equals .5, then obtained reinforcers are allocated randomly to the two alternative
responses. Davison and Baum assumed that $p_d$ would be 1 (in reality it was probably slightly less than 1) in their two-key concurrent-schedule procedure. Thus, the accumulation process described in Equations 2.5 and 2.6 means that as successive reinforcers were obtained, preference would become more and more extreme. At steady-state levels the model would predict strict matching (if $p_d = 1$), or undermatching (when $p_d < 1$). As with the cumulative-effects model, no upper limits were specified for the accumulations.

However, Davison and Baum (2000) specified two further mechanisms that served to limit the reinforcer accumulations, and to fit their data better. They noted that as preference changed quickly in response to individual reinforcers at the beginning of a component, events in the more distant past must have less effect on current preference. If reinforcer accumulations rose indefinitely, behaviour would become completely insensitive to changes in the reinforcer ratio. Davison and Baum suggested that with the passage of time, reinforcers would be lost from each accumulation at a particular rate. Thus, the accumulations would stay reasonably low, and allow the fast changes in preference evident in their data. Davison and Baum also noted that, during the blackouts they arranged between components, preference regressed towards indifference. The reinforcer-loss process described above could not account for this. A third process, in which the reinforcer accumulations became less differential with the passage of time, was therefore added. These two processes work in combination with the process shown in Equations 2.5 and 2.6, as follows:

$$R'_{ij} = p \Delta p_e R'_{i,j-1} + (1 - p \Delta) p_e R'_{r,j-1}, \quad (2.7)$$

and

$$R'_{r,j} = p \Delta p_e R'_{r,j-1} + (1 - p \Delta) p_e R'_{r,j-1}, \quad (2.8)$$
The parameters are as shown in Equations 2.5 and 2.6. Equations 2.7 and 2.8 are to be applied at the end of every (arbitrary) fixed time unit. The size of this time unit determines the values of the parameters $p_{\Delta}$ and $p_e$. At the end of each time unit, both within components and during the blackout between components, some reinforcers are lost from the accumulations $[(1-p_e) R'_{t,t-1} + (1-p_e) R'_{t+1,t-1}]$. Equations 2.7 and 2.8, conversely, show the proportion of reinforcers that are not lost, the parameter $p_e$, therefore, is best interpreted as a discriminability parameter between those reinforcers arranged in the experimental setting and extraneous reinforcers (Herrnstein, 1970), and was termed arranged-extraneous discriminability by Davison and Baum. Thus, if $p_e$ is 1 all reinforcers are retained in the accumulations, and if it is .5 half of the reinforcers in the accumulations are retained at each time unit. The parameter $p_{\Delta}$, accumulation discriminability, determines the reinforcers that are reallocated between the two accumulations at each time unit. If $p_{\Delta}$ is 1 no reallocation occurs, whereas if it is .5 the accumulations would equalise after a single time unit.

The model predicted the major features of Davison and Baum’s (2000) data. Importantly, it also predicted higher sensitivities with a higher overall rate of reinforcement. This would occur simply because there would be less reallocation of reinforcers via $p_{\Delta}$ between reinforcer deliveries. The model also predicted less carryover between components as the blackout between components was increased, a prediction subsequently confirmed by Davison and Baum (2002).

Davison and Baum’s (2000) model accounts, between components at least, for the effects of the passage of time in a more parsimonious fashion than the approach used by Mazur (1995), and also predicts the effects of rate of reinforcement that were problematic for Mazur (1997). The model also remedies the problem of the development of infinitely large accumulations evident with the cumulative-effects
model. Unlike Mazur, Davison and Baum did not examine their data session-by-session so no comment was made on changes that might occur between sessions. The same processes would be unlikely to apply between sessions, although this might not be detectable in Davison and Baum’s procedure where accumulations would be consistently low. In steady-state concurrent schedules it would be unlikely that accumulations would decrease and equalise at same relatively high rates in the approximately 23 hours between sessions, as evidenced by Davison and Hunter’s (1979) finding control by a previous session’s reinforcer ratio three or four sessions after the reinforcer ratio had changed.

2.5 Summary

The research investigating behaviour in conditions that vary in terms of environmental stability has shown collectively, as might be expected, that reinforcer ratios arranged previously (both in previous sessions, and previously in the same session) affect current behaviour. However, the degree of this control by previous reinforcer ratios is affected by the frequency of environmental change. Across studies, Davison and Hunter (1979) changed the reinforcer ratio in effect every six sessions and control was evident three or four sessions after a change. Schofield and Davison (1997) arranged changes every session, and with extended training found that control was evident only by the present session’s reinforcer ratio. Finally, Davison and Baum (2000) arranged seven different reinforcer ratios within a single session, and found control by the previous-component reinforcer ratio five or six reinforcers into the present component. To summarise, control became more localised as the environments changed more frequently. Davison and Baum (2000) identified an apparent ceiling to this effect. When they manipulated the frequency of
environmental change by changing the number of reinforcers per component in their procedure, no effect of the frequency of environmental change was evident.

Davison and Baum (2002) and Mazur (1996) independently showed that the passage of time affects control by a previous reinforcer ratio. Mazur introduced a three-session “rest period” between sessions in a version of his generic procedure and found that the spontaneous recovery effects he had observed were still present, but greatly reduced. Davison and Baum showed that the control exerted by a previous-component reinforcer ratio decreased as the blackout arranged between components was increased. However, given the large differences in time frames between these two procedures, it is doubtful that they arise from the same process. Importantly, Mazur showed that the spontaneous recovery effects he observed were not simply a regression towards indifference. He showed that spontaneous recovery could be observed towards both more and less extreme preferences, dependent on the reinforcer ratio in effect previously. Davison and Baum observed a regression towards indifference in their procedure when they arranged unsignaled extinction. However, as they acknowledged, this also would have been predicted if this movement in preference was controlled by the molar reinforcer ratio in their procedure.

The overall rate of reinforcement also has a clear effect on behaviour in these conditions. Steady-state concurrent-schedule research has shown that sensitivity to reinforcement changes with the overall rate of reinforcement (Alsop & Elliffe, 1988; Elliffe & Alsop, 1996). Similar results have been reported in the research outlined above: Davison and Baum (2000), Dreyfus (1991), and Mazur (1997) have shown, in a variety of procedures, that behaviour changes more quickly when the overall rate of reinforcement is higher.
Numerous models of event integration have been proposed to account for these and other data. None, it seems, can at this stage account for all the data in the literature. The brief review here suggests that the accumulation approach, exemplified in the cumulative-effects model (Davis et al., 1993) and more recently Davison and Baum's (2000) model, holds the greatest promise.
3.1 Experiment 1a

Davison and Baum (2000) adapted a procedure introduced by Belke and Heyman (1994) to study behaviour under conditions in which the environment changed very rapidly. They arranged seven different reinforcer ratios (27:1, 9:1, 3:1, 1:1, 1:3, 1:9, and 1:27) in a single session. These components were presented in a random order, and separated by 10-s blackouts. In Part 1, Davison and Baum varied the speed of environmental change by altering the number of reinforcers presented per component between four and twelve across a series of conditions. In Part 2, they varied the overall reinforcer rate with components either four or twelve reinforcers in length.

Using sensitivity to reinforcement as a function of successive reinforcer deliveries as a measure of the rate of behaviour change within a component, Davison and Baum (2000) found no effect of component length. However, the speed at which behaviour changed within components was very rapid, with sensitivity to reinforcement reaching moderately high levels (about 0.60) after just six to eight reinforcer deliveries in a component. This rate of behavioural change was faster when the overall rate of reinforcement was higher, as reported in previous research examining behaviour in variable conditions (Dreyfus, 1991; Mazur, 1997), and analogous to steady-state findings (Alsop & Elliffe, 1988; Elliffe & Alsop, 1996). Davison and Baum also reported that individual reinforcers, and sequences of reinforcers, had regular effects on behaviour. Specifically, successive reinforcers obtained from the same alternative had decreasing effects on behaviour, while reinforcers obtained from the other alternative had comparatively large effects on behaviour.
The present experiment used the same basic procedure as Davison and Baum (2000), but the range of within-session reinforcer ratios was explicitly manipulated. Throughout the present experiment both the overall rate of reinforcement (2.22 per min), and the number of reinforcers per component (10), were held constant. Across conditions, the range of reinforcer ratios available was varied from a condition in which the reinforcer ratio was always 1, to one in which they were varied from concurrent VI 27-s extinction to concurrent extinction VI 27-s. Some of the following data and analyses have been presented elsewhere (Landon, 1999; Landon & Davison, 2001).

3.2 Method

Subjects

The subjects were six homing pigeons numbered 61 to 66. All subjects apart from Bird 64 were maintained at 85% ± 15 g of their free-feeding body weights. Bird 64 could not be maintained at this level of deprivation with the number of reinforcers arranged in each session, and was therefore maintained at 90% ± 15 g of its free-feeding body weight. The subjects were maintained at their designated body weights by post-session feedings of mixed grain. Water and grit were freely available to all subjects at all times.

Apparatus

Each bird was housed in a cage 380 mm high, 380 mm wide, and 380 mm deep. The back, left, and right walls of each cage were constructed of sheet metal, while the top, floor, and front wall of the cage consisted of metal bars. Each cage contained two wooden perches mounted 50 mm from the chamber floor. One was mounted 95 mm from, and parallel to, the front wall, and the second mounted 95 mm
from, and parallel to, the right wall. Illumination was provided by the ambient room lighting, and there was no sound attenuation.

The right wall of each cage contained three translucent response keys, 20 mm in diameter, centred 100 mm apart, and 200 mm above the perches. The centre key was always dark and inoperative. The two side keys could be transilluminated yellow and, when lit, operated by pecks exceeding a force of about 0.10 N. A hopper containing wheat was located behind a 50 mm by 50 mm aperture situated 145 mm below the centre key. During reinforcer delivery, the hopper was raised and illuminated for 2.5 s and the keylights extinguished. From the home cages, other pigeons working on other experiments were visible and audible, but no personnel entered the room while the experiments were running. The experimental room was lit from 1 am to 4 pm, and sessions began at 1:30 am. The subjects were run successively, and all experimental events were arranged on an IBM®-PC compatible computer running MED-PC® software, situated remote from the experimental cages. The computer also recorded the time at which every event occurred within the experimental sessions.

Procedure

A two-key concurrent-schedule procedure was used, and sessions began with both side keys lit yellow. Once ten reinforcers had been obtained, both key lights were extinguished, and a 10-s blackout ensued. At the conclusion of the blackout, the next component began with the side keys again lit yellow. Each session consisted of seven such components. Sessions were conducted daily, and ended in blackout following the completion of the seven components, or after 45 min had elapsed, whichever occurred first.
Immediately prior to the beginning of each component, the computer selected the next component randomly without replacement from a list (see Table 3.1). Thus, subjects were exposed to seven different pairs of concurrent VI schedules during each session. Reinforcers were scheduled according to a single exponential VI 27-s schedule ($p = .037/s$). Once a reinforcer was arranged, it was allocated to one of the alternatives according to the probability selected, as shown in Table 3.1. Reinforcers were dependently scheduled (Stubbs & Pliskoff, 1969): Once a reinforcer was arranged on one alternative, no further reinforcers could be arranged until it had been obtained. A 2-s changeover delay (Herrnstein, 1961) prevented responses from producing an arranged reinforcer on a given alternative until 2 s had elapsed since the first response on that alternative following a response on the other alternative. Once a reinforcer was arranged on an alternative, and if the changeover delay had completed timing, the next effective response to that alternative was reinforced.

The subjects had experience on a foraging procedure similar to that reported by Jones and Davison (1996). Thus, neither magazine nor key-pecking training was necessary. However, some preliminary training on the experimental procedure was carried out. This training was used to reduce gradually the probability of reinforcement per second to the experimental value of .037, and to introduce the changeover delay. During preliminary training, the probability of a reinforcer being allocated to either key was always .50.
Table 3.1

Sequence of experimental conditions and relative reinforcer probability (shown as probability of reinforcement on the left alternative) for each of the seven components in each condition in Experiment 1a. The overall probability of reinforcement per second was constant at .037 throughout.

<table>
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<th>Component</th>
<th>Relative reinforcer probability $p (L)$</th>
<th>Reinforcer ratio (L:R)</th>
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The sequence of experimental conditions, relative reinforcer probabilities, and the arranged reinforcer ratios in each component are shown in Table 3.1. Across conditions, the range over which the seven reinforcer ratios were varied was manipulated. Experiment 1a consisted of Conditions 1 to 8, and Condition 16. In Conditions 1 and 6, the reinforcer ratios were varied from 1:27 to 27:1, the same range used by Davison and Baum (2000). Condition 2 was discarded due to a
programming error. The remaining conditions presented varying ranges of reinforcer ratios, from the least extreme, Condition 8, where the reinforcer ratio was always 1:1, to Condition 16 where they varied from Ext:1 to 1:Ext. No stability criterion was in effect. However, given the brief within-session exposures to each reinforcer ratio, fifty sessions were conducted for each condition to ensure sufficient data were collected to be comparable to five sessions of steady-state data, as is commonly used in steady-state research (Davison & Baum, 2000). The data obtained from the last 35 sessions of each condition were used in the analyses.

3.3 Results

The data used in the following analyses consisted of the time of every experimental event, and are therefore too extensive to include in an Appendix. Davison and Baum (2000) established that in a procedure very similar to the present one, behaviour changed within components with successive reinforcer deliveries. Moreover, the degree of the change in behaviour was directly related to the reinforcer ratio in effect in that component. Figures 3.1 and 3.2 show the changes in individual-subject and group response allocation as a function of successive reinforcer deliveries for Conditions 5 (3.38:1 to 1:3.38) and 6 (27:1 to 1:27). In components in which reinforcer ratios other than 1:1 were arranged, preference moved towards the alternative providing the higher rate of reinforcement. This movement in preference was directly related to the reinforcer ratio in effect in that component. As established earlier (Landon and Davison, 2001), the group data, that is the data summed across individual subjects, provide a reasonably accurate representation of the major effects evident in the data obtained from the individual subjects. This is important, as many of the subsequent analyses will present only group data.
Figure 3.1. Log response ratios emitted by each subject and the group following each successive reinforcer delivered in each of the seven components of Condition 5. Response numbers for each alternative were summed across all 35 sessions. On the x-axis, 0 indicates the log response ratio emitted prior to the first reinforcer delivery in a component.
Figure 3.2. Log response ratios emitted by each subject and the group following each successive reinforcer delivered in each of the seven components of Condition 6. See Figure 3.1 for details.
3.3.1 *Multiple linear regression analyses*

Davison and Baum (2000) showed that multiple linear regressions based on a GML approach could be used to assess the linear contribution of the reinforcer ratio in the current component (current-component sensitivity), and the reinforcer ratio in the previous component (previous-component sensitivity) on performance prior to each successive reinforcer delivery in the current component (see also Davison & Hunter, 1979). The equation for this analysis is:

\[
\log \left( \frac{B_{ln}}{B_{rm}} \right) = a_{pn} \log \left( \frac{R_{lp}}{R_{rp}} \right) + a_{cn} \log \left( \frac{R_{lc}}{R_{rc}} \right) + \log c, \quad (3.1)
\]

where the subscripts \( l \) and \( r \) refer to the left and right alternatives, \( p \) and \( c \) refer to the previous and current components, and \( n \) refers to the reinforcer number in a component. In each condition the numbers of responses emitted at each of the two alternatives were summed separately for each component, for the periods before the first reinforcer in a component, between the first and second reinforcers in a component, and so on. Equation 3.1 was fit to these data. For Condition 16, the equation was fit to five data points as the most extreme reinforcer ratios arranged (Ext:1 and 1:Ext) were infinite. Data from Condition 8 were omitted from these analyses as no variation was arranged in the component reinforcer ratios.

Figure 3.3 shows sensitivity to the current- and previous-component reinforcer ratios plotted as a function of successive reinforcer deliveries in a component. At the start of a component, sensitivity to the previous-component reinforcer ratio was above zero (range 0.15 to 0.37), and fell towards zero with successive reinforcer deliveries. This was true for each of the individual subjects, with one exception: Bird 66 in Condition 7 had an initial sensitivity of -0.08. After four reinforcer deliveries in the current component, sensitivity to the previous-component reinforcer ratio was still
above zero (range 0.08 to 0.22), and this pattern persisted even after six reinforcer deliveries (range 0.04 to 0.15). Examination of the individual subjects showed the data obtained from Condition 7 were more variable, as was evident in the group data from this condition. Nevertheless, of the 30 sensitivity values calculated up to and after the fourth reinforcer delivery in a component in Condition 7, only seven were less than 0. For the remaining conditions, after the fourth reinforcer delivery in a component, 33 of the 36 sensitivity values calculated were greater than 0 (range -0.08 to 0.31).

Figure 3.3 also shows that sensitivity to the current-component reinforcer ratio started close to zero (range 0 to -0.02), and increased to a mean value of 0.46 (range 0.32 to 0.79) after nine reinforcer deliveries in a component. Similar effects were evident in the individual data: Initial sensitivity values were close to zero (range − 0.14 to 0.15), with more variable data again evident in Condition 7. Thereafter, sensitivity generally increased with successive reinforcers. As described by Davison and Baum (2000), the difference between final sensitivity to the current reinforcer ratio and the starting sensitivity to the previous-component reinforcer ratio shows the effect of the between-component blackout.
Figure 3.3. Sensitivity to reinforcement values from multiple linear regressions between log response ratios and arranged log reinforcer ratios (Equation 3.1) in the previous and current components for each successive reinforcer delivery. Each panel represents data from a different condition in Experiment 1a. Response numbers were summed across all six subjects.
In addition to the increase in current-component sensitivity and the corresponding decrease in previous-component sensitivity, Figure 3.3 shows an effect of the range of reinforcer ratios on current-component sensitivity. That is, as the range of reinforcer ratios was increased across conditions, current-component sensitivity also increased. To investigate these effects more closely, two-way repeated-measures ANOVAs were used to examine the effects of the sequential position of the reinforcer in the component, and the range of reinforcer ratios on current-component sensitivity values obtained for the individual subjects. Sensitivity values obtained prior to any reinforcers being obtained in a component were omitted from these analyses, and separate ANOVAs were conducted using Conditions 3, 4, 5, 7, either Condition 1 or 6, and Condition 16. When Condition 6 was used in the analysis, significant effects were evident for both the range of reinforcer ratios ($F_{4,200} = 8.03, p < .05$), and the sequential position of the reinforcer ($F_{7,200} = 4.35, p < .05$). Both effects were also evident when the analysis was repeated with Condition 1 in place of Condition 6 ($F_{4,200} = 3.03, p < .05$, and $F_{7,200} = 3.115, p < .05$, respectively). Similar analyses to those reported above were carried out on the values obtained for sensitivity to the previous-component reinforcer ratio. Due to the nature of carryover, these ANOVAs included the sensitivity values obtained prior to the first reinforcer delivery in a component. Using Condition 6, no effect of the range of reinforcer ratios was evident ($F_{4,225} = 0.40, p > .05$). However, as is clear in Figure 3.3, there was an effect of the sequential position of the reinforcer ($F_{8,225} = 10.04, p < .05$). These effects were replicated when Condition 1 was used in place of Condition 6 ($F_{4,225} = 0.01, p > .05$, and $F_{8,225} = 9.08, p < .05$, respectively). Thus, sensitivity to the previous-component reinforcer ratio decreased with successive reinforcers in the
current component. However, there was no effect of the range of reinforcer ratios on the amount of control exerted by the previous-component reinforcer ratio.

3.3.2 Reinforcer-by-reinforcer analyses

The effects of individual reinforcers on behaviour were examined using a more local analysis. The data were aggregated across subjects into log response ratios emitted in inter-reinforcer intervals following every possible sequence of up to eight reinforcers in each condition. Specifically, before the first reinforcer in a component a particular average response ratio was emitted, and a log response ratio could be calculated. Following the first reinforcer and before the second, two log response ratios were available (one following a left-alternative reinforcer, and one following a right-alternative reinforcer), and two log response ratios could be calculated. Following the second reinforcer in a component, there were four response ratios available, one for each of the possible two-reinforcer sequences, and so on throughout a component.

Landon and Davison (2001, their Figure 5) showed regular effects on behaviour of all possible sequences of the first four reinforcers in a component. They showed that the effect of a given reinforcer was dependent on the context in which it was obtained: Preference moved more in conditions in which a greater range of reinforcer ratios was arranged; and, within conditions, a reinforcer had a greater effect on behaviour when it was obtained from the alternative opposite to that which the preceding reinforcer was obtained (a disconfirmation).

To examine behaviour following various sequences of reinforcers deeper into components, Figure 3.4 shows only a portion of the tree structures from Conditions 8, 5, 3, 4, 6, and 16. The log response ratios emitted in inter-reinforcer intervals
following sequences of successive left-alternative (or right-alternative) reinforcers are shown, as are the log response ratios emitted after a disconfirmation at each sequential position. Each of the 72 disconfirmations shown in Figure 3.4 moved preference towards the alternative from which it was obtained. Nonparametric tests for trend (Ferguson, 1966) were used to assess any trends in the effects of disconfirmations and confirmations with successive reinforcer deliveries in a component. The means of the changes in log response ratios following disconfirmations and confirmations were calculated at each sequential position. The change in preference resulting from a disconfirmation increased as a function of the sequential position of the reinforcer in a component \( (N = 8 \text{ conditions, } k = 7 \text{ reinforcers, } z = 4.05, p < .05) \). A similar trend test showed that the effects of confirming reinforcers had the opposite effect: That is, their effects decreased as a function of the sequential position of the reinforcer in a component \( (N = 8 \text{ conditions, } k = 7 \text{ reinforcers, } z = 3.14, p < .05) \).
Figure 3.4. Log response ratios emitted in inter-reinforcer intervals following successive same-alternative reinforcers (solid lines) in Conditions 3, 4, 5, 6, 8, and 16 in Experiment 1a. The broken lines join “disconfirmations” where a reinforcer was obtained from the other alternative following sequences of same-alternative reinforcers.

The finding reported by Davison and Baum (2000) that disconfirmations have comparatively large effects on preference was replicated here. Figure 3.4 also shows that across conditions preference following a disconfirmation was similar irrespective
of the range of reinforcer ratios arranged in a condition. Specifically, preference following the first two or three disconfirmations “crossed over” so that the alternative at which the disconfirmation was obtained was preferred. Following subsequent disconfirmations, preference reverted to levels that approximated indifference. This indifference was biased towards the right alternative given the behaviour of all subjects was biased to some degree to the right alternative (see Landon & Davison, 2001). Thus, the trends in the effects of disconfirmations were due to preference being at more extreme levels prior to a disconfirmation deeper in a component when the range of reinforcer ratios was greater, rather than preferences being different following the disconfirmations.

Given these regularities, it is of some interest to examine preference with various sequences of reinforcers obtained following a disconfirmation. Thus, sequences of three successive left- or right-alternative reinforcers were isolated and compared. The first were sequences of three successive left- or right-alternative reinforcers at the start of a component, the next were the same sequences following left-right (LR) or right-left (RL) sequences. These same sequences were examined following LLR, RRL, LLLR, RRRL, LLLLR, and RRRL sequences. These sequences were examined both when the three successive reinforcers were obtained from the same alternative as the disconfirmation, and from the opposite alternative as the disconfirmation.
Figure 3.5. Log response ratios emitted in inter-reinforcer intervals following sequences of three successive same-alternative reinforcers in Conditions 3, 6, and 8. The three successive reinforcers occurred at the beginning of a component, or following "disconfirmations," which were the second, third, fourth, or fifth reinforcer in a component following a sequence of successive reinforcers obtained on the other alternative (left panels) or the same alternative (right panels).

Figure 3.5 shows the results of these analyses for Conditions 3, 6, and 8. These conditions are representative of performance in other conditions, and provide
comparisons across varying distributions of reinforcer ratios. The left panels show the effects on behaviour of three successive reinforcers obtained from the alternative opposite to that at which the disconfirmation starting the sequence was obtained. Whereas the right panels show three successive reinforcers obtained at the same alternative as the disconfirmation. To facilitate comparison, all sequences have been plotted from 0 to 3 on the x-axis, and the symbols denote the position in a component from which the sequences were obtained.

Figure 3.5 shows the preference reversals caused by disconfirmations obtained early in components. This crossing over was most noticeable (0 on the x-axis) following the first disconfirmation (open triangles), followed by the second disconfirmation (open squares). Thereafter, preference following a disconfirmation was similar to that observed at the beginning of a component (filled circles). Figure 3.5 also shows that the log response ratios emitted with each successive reinforcer following a disconfirmation, and those emitted at the beginning of a component, were largely superimposable within each condition. The next reinforcer, regardless of which alternative this reinforcer was obtained at, immediately negated the crossover effect following an early disconfirmation. The log response ratios emitted after subsequent same-alternative reinforcers were similar to those emitted when that same sequence of reinforcers was obtained at the beginning of a component.

3.3.3 Behaviour in inter-reinforcer intervals

An even more local analysis was used to examine the changes in preference during inter-reinforcer intervals following each successive reinforcer delivery in a component. The responses emitted following the first reinforcer in a component were collated across all subjects into 2-s time bins following left- and right-alternative
reinforcers separately. Then, two sets of log response ratio emitted in each successive 2-s time bin could be calculated: One when the first reinforcer was obtained at the left alternative; and one when the first reinforcer was obtained at the right alternative. This process could then be repeated for every possible sequence of the first nine reinforcer deliveries in a component (components ended after ten reinforcer deliveries).

The log response ratios emitted in successive 2-s bins following sequences of successive left- or right-alternative reinforcers that varied in length were then isolated and compared. Figures 3.6 to 3.9 show these log response ratios for Conditions 16, 4, 3, and 7, respectively. It should be noted that in some conditions long sequences of successive reinforcers obtained from the same alternative were very rare. Thus, the variability evident in the data obtained following such long sequences in Condition 7 (Figure 3.9) can be attributed to their infrequent occurrence. The data missing at the leftmost end of the panels are where the response ratio emitted was exclusive to one alternative, and it was therefore impossible to calculate a log response ratio. Two major effects are evident in Figures 3.6 to 3.9: First, across conditions the change in preference resulting from a given reinforcer increased as the range of reinforcer ratios was increased; second, within conditions, the preference remained at more extreme levels for longer as successive reinforcers were obtained from the same alternative. This finding was evident even when the range of reinforcer ratios arranged was very narrow. For example, if Condition 7 (1.5:1 to 1:1.5, Figure 3.9) is considered, preference following the first reinforcer in a component has returned to a stable level by about 6 s after the reinforcer. After the second reinforcer (first confirmation) this did not occur until 8 to 10 s, and after the second and third confirmations this did not occur until about 12-s after the reinforcer. These effects become clearer as the range
of reinforcer range of reinforcer ratios was increased. In Condition 3 (8:1 to 1:8, Figure 3.8), with the exception of the first reinforcer in a component, preference following a right reinforcer consistently favoured that alternative, and this difference increased with successive reinforcers obtained at the same alternative. While in Figure Condition 16 (1:Ext to Ext:1, Figure 3.6), even 40 seconds after a reinforcer preference had not approached similar levels, nor had it apparently stabilised.
Figure 3.6. The log response ratios emitted in successive 2-s time bins in Condition 16 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.7. The log response ratios emitted in successive 2-s time bins in Condition 4 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.8. The log response ratios emitted in successive 2-s time bins in Condition 3 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.9. The log response ratios emitted in successive 2-s time bins in Condition 7 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.10. The differences between the log response ratios emitted following successive left- and right-alternative confirming reinforcers, plotted as a function of the sequential position of the reinforcer in a component for the first, second, fourth, eighth, and sixteenth 2-s bin following a reinforcer delivery in Conditions 16, 6, 4, 3, 5, and 7.
The differences between the log response ratios emitted following left and right reinforcers were calculated and are plotted in Figure 3.10 for the first, second, fourth, eighth and sixteenth 2-s bins following a reinforcer delivery as a function of the sequential position of the reinforcer in a component for Conditions 16, 6, 4, 3, 5, and 7. Again, a number of data points are missing due to preference being exclusive following a reinforcer at one or both alternatives. The increasing differences between the log response ratios emitted following successive reinforcers show the increasing effects of successive reinforcers within each condition. In addition, the decreasing effects of reinforcers with time since reinforcement are apparent, as with each time bin plotted these differences became smaller. Finally, the changes in the duration of the effects of reinforcement across conditions were evident, most obviously in the later time bins. In Condition 16 (1:Ext to Ext:1), the data are strictly ordered – the differences between the log response ratios emitted after a left or right reinforcer became smaller as bin number increased. In Conditions 6 (27:1 to 1:27), 4 (15.63:1 to 1:15.63) and 3 (8:1 to 1:8), the performance in the eighth and sixteenth 2-s bin was very similar. Finally in Conditions 5 (3.58:1 to 1:3.58) and 7 (1.5:1 to 1:1.5), performance in the fourth, eighth, and sixteenth bins was very similar.
Figure 3.11. The log response ratios emitted in successive 2-s time bins in Condition 16 following sequences of successive same-alternative reinforcers that ended with a single "disconfirmation", and began at the start of a component.
Figure 3.12. The log response ratios emitted in successive 2-s time bins in Condition 4 following sequences of successive same-alternative reinforcers that ended with a single "disconfirmation", and began at the start of a component.
Figure 3.13. The log response ratios emitted in successive 2-s time bins in Condition 3 following sequences of successive same-alternative reinforcers that ended with a single "disconfirmation", and began at the start of a component.
CONDITION 7 (1.5:1 TO 1:1.5)

L OR R

RL OR LR

RRL OR LLR

RRRL OR LLLR

RRRRL OR LLLLLR

TIME SINCE REINFORCEMENT (2-s BINS)

LOG LR RESPONSE RATIO

Figure 3.14. The log response ratios emitted in successive 2-s time bins in Condition 7 following sequences of successive same-alternative reinforcers that ended with a single “disconfirmation”, and began at the start of a component.

Figures 3.11 to 3.14 show the log response ratios emitted in successive 2-s bins following sequences of successive left- or right-alternative reinforcers that ended with a single disconfirmation. These data are again shown for Conditions 16, 4, 3, and 7, respectively. Figures 3.11 to 3.14 show that the changes in the log response
ratios emitted after disconfirmations were relatively consistent throughout a component. Moreover, they were small, both in terms of their initial magnitudes and their durations, when compared to those shown in Figures 3.6 to 3.9. To clarify these effects, Figure 3.15 plots the differences between the log response ratios emitted after a disconfirmation that followed sequences of same alternative reinforcers that varied in their length in Conditions 16, 6, 4, 3, 5, and 7. Figure 3.15 shows that the differences between the log response ratios emitted following a disconfirmation decreased as the preceding sequence of confirming reinforcers increased. The same general patterns observed with confirmations were also evident here. The decreasing effects of reinforcers with time since reinforcement were apparent, as were the changes in the duration of the effects of reinforcement across conditions.

3.3.4 Reinforcer sequences and response rates

Given the focus on sequences of reinforcers obtained at the same alternative, and those sequences followed by disconfirmations, it is of some interest to examine how often those sequences occurred. Figure 3.16 shows the proportions of all sequences that were of the specific types under consideration (i.e., the proportion of all six-reinforcer sequences that were of the type shown, the proportion of all five-reinforcer sequences that were of the type shown, and so on). In Conditions 7 (1.5:1 to 1:1.5) and 8 (all 1:1), all sequences occurred approximately equally often. In Conditions 3 (8:1 to 1:8), 4 (15.63:1 to 1:15.63), 6 (27:1 to 1:27), and 16 (VI:Ext to Ext:VI), however, sequences of successive reinforcers obtained at either alternative were substantially more frequent. In Condition 16 (VI:Ext to Ext:VI), for example, in approximately half of all components the first six reinforcers were obtained at one
alternative. In Condition 3 (8:1 to 1:8) approximately half of the components began with three reinforcers being obtained at the same alternative.

Figures 3.17 to 3.20 show the mean number of responses emitted in each 2-s bin following a reinforcer delivery for each of the first six reinforcers obtained in a component where those reinforcers were either a sequence of reinforcers obtained at the same alternative, or a sequence of reinforcers obtained at the same alternative followed by a disconfirmation, for Conditions 16, 4, 3, and 7 respectively. The number of responses emitted in each 2-s bin was reasonably constant both across conditions and with successive reinforcers in each condition. In general however, the response rate following a right reinforcer was higher than that following a left reinforcer irrespective of whether that reinforcer was obtained at the same alternative as the preceding reinforcer, or was a disconfirmation. This effect was particularly noticeable in the first three or four 2-s bins following a reinforcer delivery, and exaggerated when the left reinforcer was also a disconfirmation.
Figure 3.15. The differences between the log response ratios emitted after “disconfirmations” which followed a sequences of successive left- or right-alternative confirming reinforcers, plotted as a function of the sequential position of the reinforcer in a component for the first, second, fourth, eighth, and sixteenth 2-s bin following a reinforcer delivery in Conditions 16, 6, 4, 3, 5, and 7.
Figure 3.16. The proportions of all sequences one to six reinforcers in length that consisted exclusively of successive reinforcers at one alternative, or successive reinforcers at one alternative followed by a single "disconfirmation" in Experiment 1a.
Figure 3.17. The mean number of responses emitted in each successive 2-s bin following sequences one to six reinforcers in length that were successive confirmations or successive confirmations followed by a single disconfirmation in Condition 16.
Figure 3.18. The mean number of responses emitted in each successive 2-s bin following sequences one to six reinforcers in length that were successive confirmations or successive confirmations followed by a single disconfirmation in Condition 4.
Figure 3.19. The mean number of responses emitted in each successive 2-s bin following sequences one to six reinforcers in length that were successive confirmations or successive confirmations followed by a single disconfirmation in Condition 3.
Figure 3.20. The mean number of responses emitted in each successive 2-s bin following sequences one to six reinforcers in length that were successive confirmations or successive confirmations followed by a single disconfirmation in Condition 7.
3.4 Discussion

The present experiment was designed to examine the effects of the range of within-session changes in the reinforcer ratio available from two response alternatives on behaviour. Various analyses were used (some of which have also been reported in Landon & Davison, 2001) to examine these effects at molar and more local levels of analysis.

Within components, log response ratios adjusted rapidly as successive reinforcers were delivered and the degree of this shift was directly related to the reinforcer ratio in effect in that component (Davison & Baum, 2000; Landon & Davison, 2001). Multiple linear regression analyses showed the contributions of previous-component and current-component reinforcer ratios to behaviour prior to each reinforcer delivery in a component. These analyses showed a clear effect of the range of reinforcer ratios arranged on sensitivity to the current-component reinforcer ratios, but no such effect on control by the previous-component reinforcer ratio.

More local, reinforcer-by-reinforcer, analyses showed regularities in the effects of individual reinforcers: Each reinforcer moved the subsequently emitted preference towards the alternative from which it was obtained. Across conditions, the effects of individual reinforcers increased as a function of the range of reinforcer ratios arranged. Within conditions, it was particularly noticeable that, compared to confirming reinforcers, disconfirmations had large effects on preference. Moreover, at this level of analysis, the effects of disconfirmations on preference increased throughout components, whereas the effects of confirmations decreased. These results have been discussed extensively elsewhere (Landon & Davison, 2001).

The analyses of behaviour during inter-reinforcer intervals have not yet been reported elsewhere, and provide some indications as to how the reinforcer-by-
reinforcer results might arise. Figures 3.6 to 3.15 showed the changes in preference during inter-reinforcer intervals following sequences of confirming reinforcers (Figures 3.6 to 3.9), and sequences of confirmations followed by a disconfirmation (Figures 3.11 to 3.14). These analyses showed the changes in preference following confirming reinforcers increased, in terms of their duration, throughout a component, while disconfirmations had smaller more brief effects on behaviour.

These results seem, at first, to contradict directly those seen in the reinforcer-by-reinforcer analyses (Figures 3.4 and 3.5). Figure 3.15 showed that disconfirmations had brief effects on behaviour, as differences in the log response ratios emitted after left or right disconfirming reinforcers were present in only the first two 2-s bins after the reinforcer delivery. These differences also became smaller as the preceding sequence of confirming reinforcers increased. This latter effect was most likely due to preference prior to the reinforcer delivery being more extreme when the preceding sequence of confirming reinforcers was longer. Across conditions, few differences between the effects of disconfirmations were evident. Thus, when the data were aggregated at a reinforcer-by-reinforcer level, disconfirmations moved preference to similar levels across conditions. However, the effects of disconfirmations were large when preferences prior to the reinforcer delivery were considered, and this perspective was provided by the reinforcer-by-reinforcer analyses.

Preferences emitted in inter-reinforcer intervals following confirming reinforcers (Figures 3.6 to 3.9) were more extreme than preferences following disconfirmations (Figures 3.11 to 3.14), and this extreme preference was maintained for longer as the sequences of confirming reinforcers increased in length, and as the range of reinforcer ratios in effect was increased (Figure 3.10). Given that response
rates were reasonably constant (Figures 3.17 to 3.20), these findings explain why sequences of confirming reinforcers shown in the tree structures had apparently small effects, and these effects changed across conditions. Within conditions, the transient movements in preference became slightly longer with each successive reinforcer delivery. Across conditions, preferences were more extreme in response to the same sequences, thus the tree structure spread wider, although the same basic structure was maintained.

As Landon and Davison (2001) reported, the behaviour of the present subjects was biased, in all cases, to the right alternative. This was evident here in the tree structures and behaviour during inter-reinforcer intervals. The analyses of response rates during inter-reinforcer intervals (Figures 3.17 to 3.20) provide some insight into how the biases arose. In all cases, in the first three to six 2-s bins following a reinforcer delivery the response rate following a right reinforcer was substantially higher than that following a left reinforcer. These differences were a little smaller, but remained present with increasing time since a reinforcer delivery. Indeed, Krägeloh (2001) has shown in a similar procedure that biases were substantially larger soon after a reinforcer delivery.

To summarise, Landon and Davison (2001) presented the present results as being due to a context effect. That is, individual reinforcers had reliable directional and quantitative effects on behaviour. The directional effects could be predicted solely from which alternative the reinforcer was obtained. The quantitative effects were also dependent on more molar factors, specifically the range of reinforcer ratios arranged, the number of reinforcers already obtained in that component, and the alternatives from which they were obtained. The present analyses change this interpretation little, except that the analysis of behaviour in inter-reinforcer intervals
suggests that sequences of confirming reinforcers were important, as their effects on behaviour seemed to increase as the sequences increased in length, and as their occurrence became more frequent across conditions. Moreover, the high proportion of sequences of these types was the main difference across conditions. In contrast, disconfirmations had reasonably similar effects within and across conditions. The changes evident within conditions in the tree structures were dependent on preference levels prior to the reinforcer delivery, rather than any changing absolute effect of disconfirmations during a component.

3.5 Experiment 1b

The context effects reported in Experiment 1a require further empirical investigation. Experiment 1b makes a procedural distinction between the range of variation in the reinforcer ratios (manipulated in Experiment 1a), and what can be termed the variation in the reinforcer ratios themselves. This was done by holding the most extreme component reinforcer ratios constant and varying the reinforcer ratios arranged in the other components.

Experiment 1a showed what appeared to be an effect of the range of within-session reinforcer ratio changes. At this stage the mechanism underlying this effect is unclear. If the most extreme reinforcer ratios are held constant (27:1 or 1:27), and the other component reinforcer ratios varied, it may be possible to delineate the effects of the range of variation and the variation itself. If a condition arranged six components (three each of either 27:1 or 1:27), it would have the same range of variation as Condition 6 in Experiment 1a (27:1, 9:1, 3:1, 1:1, 1:3, 1:9, and 1:27). The latter, however, contains more variation in the reinforcer ratios themselves. Additionally, the former arrangement would result in an increased frequency of longer sequences of
successive confirming reinforcers. The analyses presented above suggest that these sequences may have been important in producing the context effect reported in Experiment 1a.

In Experiment 1b the range of reinforcer ratios was held constant at 27:1 to 1:27, and the reinforcer ratios in less extreme components were varied across seven conditions. Conditions 9 and 15 arranged the least variation in reinforcer ratios, and also the greatest frequency of long sequences of confirming reinforcers. Six components were arranged in these conditions, with the reinforcer ratios either 27:1 or 1:27 with equal frequency. The variation was gradually increased to Condition 12, which was a replication of Conditions 1 and 6 from Experiment 1a.

3.6 Method

Subjects and Apparatus

The subjects and apparatus used in Experiment 1b were identical to those used in Experiment 1a.

Procedure

The same basic procedure as used in Experiment 1a was used again. Conditions 9, 10, 14, and 15 consisted of only six components per session. Therefore, in those four conditions sessions ended following either the completion of the six components, or after 45 min had elapsed, whichever occurred first.
Table 3.2

Sequence of experimental conditions and relative reinforcer probability (shown as probability of reinforcement on the left alternative) for each of the components in each condition in Experiment 1b. The overall probability of reinforcement per second was constant at .037 throughout.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Component</th>
<th>Relative reinforcer probability p (L)</th>
<th>Reinforcer ratio (L:R)</th>
</tr>
</thead>
<tbody>
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<td>9</td>
<td>1</td>
<td>.0357</td>
<td>1:27</td>
</tr>
<tr>
<td></td>
<td>2</td>
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The sequence of experimental conditions is shown in Table 3.2. In Conditions 9 and 15, the reinforcer ratios arranged in the six components were either 27:1 or 1:27. In Conditions 10 and 14, the reinforcer ratios were 27:1, 27:1, 3:1, 1:3, 1:27, and 1:27. In Conditions 11 and 13, seven components were arranged; the same six arranged in Conditions 10 and 14, with the addition of a 1:1 reinforcer ratio component. Finally, Condition 12 was a replication of Conditions 1 and 6 from Experiment 1a, as such seven components were arranged with reinforcer ratios of 27:1, 9:1, 3:1, 1:1, 1:3, 1:9, and 1:27. Once again no stability criterion was used. Fifty sessions were conducted for each condition, and data obtained from the last 35 sessions of each condition were used in the analyses.
3.7 Results

3.7.1 Reinforcer Sequences

Figure 3.21 shows the proportions of specific sequences of reinforcers that occurred in Conditions 9 to 15. In Conditions 9 and 15 (27:1 or 1:27), the majority of components (.79 and .81 respectively) began with a sequence of six successive reinforcers obtained at the same alternative. As the less extreme components were added across conditions, the proportions of sequences that were exclusively confirmations dropped, but they still occurred much more frequently than any others (.43 in Condition 12 (27:1 to 1:27)).
Figure 3.21. The proportions of all sequences one to six reinforcers in length that consisted exclusively of successive reinforcers at one alternative, or successive reinforcers at one alternative followed by a single "disconfirmation" in Experiment 1b.
3.7.2 *Multiple linear regression analyses*

As with Experiment 1a, in each condition the numbers of responses emitted at each alternative were summed separately for each component in the periods before each successive reinforcer delivery. Equation 3.1 was then fit to the data. Figure 3.22 shows sensitivity to the current- and previous-component reinforcer ratio plotted as a function of successive reinforcer deliveries in a component. In each condition, sensitivity to the previous-component reinforcer ratio started above zero (range, 0.25 to 0.29), this was also the case for each individual subject (range, 0.17 to 0.47). These values then fell towards zero with successive reinforcer deliveries. After four reinforcer deliveries, sensitivity to the previous-component reinforcer ratio was above zero, in all cases for the group data (range, 0.05 to 0.15), and in 34 of 42 cases for the individual subjects (range, -0.17 to 0.31).

Sensitivity to the current-component reinforcer ratio was close to zero (range – 0.02 to 0.01) prior to any reinforcers being obtained in a component. As sensitivity to the previous-component reinforcer ratio fell, sensitivity to the current-component reinforcer ratio increased with successive reinforcer deliveries. After nine reinforcer deliveries in a component the mean sensitivity to the current-component reinforcer ratio was 0.58 (range, 0.53 to 0.65). As is the case throughout, the individual data showed the same general effects. Prior to any reinforcer deliveries in a component, individual values of sensitivity to the current-component reinforcer ratio were close to zero (range, -0.15 to 0.14), and increased with successive reinforcer deliveries. While the major features of the data were similar across the replications, it was the case that sensitivity values obtained in the replications were generally larger than those obtained in the original conditions.
Figure 3.22. Sensitivity to reinforcement values from multiple linear regressions between log response ratios and arranged log reinforcer ratios (Equation 3.1) in the previous and current components for each successive reinforcer delivery. Each panel represents data from a different condition in Experiment 1b. Response numbers were summed across all six subjects.
Figure 3.22 shows evidence of an effect of the variation arranged in the reinforcer ratios on sensitivity to the current-component reinforcer ratio. That is, as this variation was increased across Conditions 9, 10, 11, and 12, sensitivity to the current-component reinforcer ratio appeared to decrease. This apparent effect was similar across Conditions 15, 14, 13, and 12. With respect to sensitivity to the previous-component reinforcer ratio, this appears to have fallen faster with successive reinforcer deliveries when less variation was arranged in the reinforcer ratios (i.e., more quickly in Condition 15, than 14, 13, and 12). This effect was more apparent in the replicated set of conditions (Conditions 12 to 15) than in the original set (Conditions 9 to 12).

To confirm these effects using the data obtained from the individual subjects, two-way repeated-measures ANOVAs were used as in Experiment 1a. These analyses were conducted separately for Conditions 9 to 12 and then Conditions 12 to 15, for both sensitivities to the current- and previous-component reinforcer ratios. For sensitivity to the current-component reinforcer ratio, values obtained prior to any reinforcers being obtained in a component were omitted. When Conditions 9 to 12 were used, significant effects were evident for both the variation arranged in reinforcer ratios ($F_{2,143} = 3.96, p < .05$), and the sequential position of the reinforcer ($F_{7,143} = 11.13, p < .05$). Both effects were also evident when the analysis was repeated with Conditions 12 to 15 ($F_{2,143} = 9.33, p < .05$, and $F_{7,143} = 12.25, p < .05$, respectively). Sensitivity to the previous-component reinforcer ratio fell with successive reinforcer deliveries in both Conditions 9 to 12 ($F_{8,161} = 27.49, p < .05$) and Conditions 12 to 15 ($F_{8,161} = 25.91, p < .05$) as is clear in Figure 3.22. However, the effect of reinforcer ratio variation on sensitivity to the previous-component
reinforcer ratio was significant for Conditions 12 to 15 ($F_{2,161} = 5.48, p < .05$), but not Conditions 9 to 12 ($F_{2,161} = 1.28, p > .05$).

3.7.3 Reinforcer-by-reinforcer analyses

The reinforcer-by-reinforcer analyses reported in Experiment 1a were repeated using the present data. The log response ratios emitted in inter-reinforcer intervals following every possible sequence of reinforcers were calculated. Landon and Davison's (2001) Figure 11 shows these analyses for every possible sequence of the first four reinforcers in a component. They showed again that each reinforcer moved preference towards the alternative at which it was obtained.

Figure 3.23 shows only part of the tree structures. As with Figure 3.4, log response ratios following sequences of successive reinforcers obtained at either alternative are shown, along with log response ratios following a disconfirmation at each sequential position. Again it is apparent that disconfirmations had very large effects on preference, and these effects increased with component reinforcer number. In contrast, successive confirming reinforcers had diminishing effects on preference. Nonparametric tests for trend (Ferguson, 1966) confirmed these effects: The change in preference following disconfirmations increased with the sequential position of the reinforcer ($N = 7$ conditions, $k = 6$ reinforcers: $z = 5.40, p < .05$); while confirming reinforcers had diminishing effects ($N = 7$ conditions, $k = 7$ reinforcers: $z = 4.54, p < .05$).
Figure 3.23. Log response ratios emitted in inter-reinforcer intervals following successive same-alternative reinforcers (solid lines) in Conditions 9 to 15. The broken lines join "disconfirmations," where a reinforcer was obtained from the other alternative following a sequence of same-alternative reinforcers.
Figure 3.23 shows some clear differences between the present data and those shown in Figure 3.4. In Conditions 9 and 15, disconfirmations resulted in reversals in preference regardless of their sequential position in a component. In contrast, in Figure 3.4 such reversals occurred reliably only when the disconfirmation was the second, third or fourth reinforce in a component. In Conditions 10 and 14, these crossovers occurred when the disconfirmation was the fifth or sixth reinforce in a component, whereas Conditions 11, 12, and 13 showed the same patterns as conditions from Experiment 1a.

3.7.4 Behaviour in inter-reinforcer intervals

Figures 3.24 to 3.27 show the log left/right response ratios emitted in successive 2-s time bins following sequences of successive reinforces obtained at the same alternative for Conditions 9, 10, 11, and 12, respectively. In some cases, soon after a reinforce delivery, data points have been omitted as responding was exclusive to the alternative at which a reinforce was just obtained. These figures show that, within conditions, with successive reinforces obtained at the same alternative, the resulting changes in preference became both more extreme and longer in duration. Furthermore, following every sequence of reinforces shown in each condition, even as long as 40 s after a reinforce delivery, preference favoured the alternative at which a reinforce was most recently obtained.
Figure 3.24. The log response ratios emitted in successive 2-s time bins in Condition 9 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.25. The log response ratios emitted in successive 2-s time bins in Condition 10 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.26. The log response ratios emitted in successive 2-s time bins in Condition 11 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.27. The log response ratios emitted in successive 2-s time bins in Condition 12 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.28. The differences between the log response ratios emitted following successive left- and right-alternative confirming reinforcers plotted as a function of the sequential position of the reinforcer in a component for the first, second, fourth, eighth, and sixteenth 2-s bin following a reinforcer delivery in Conditions 9 to 15.
Figure 3.28 shows the differences between the log response ratios emitted following sequences of reinforcers obtained at the same alternative for the first, second, fourth, eighth, and sixteenth 2-s bin following a reinforcer delivery. The generally increasing differences at each time bin within each condition show that each successive reinforcer had an increasing effect. Across conditions, few effects are apparent. The magnitudes of the differences in log response ratios were similar across conditions. As was evident in Figures 3.24 to 3.27, even in the sixteenth 2-s bin following a reinforcer delivery, the log response ratios following left and right reinforcers differed.

Figures 3.29 to 3.32 show the log response ratios emitted in successive 2-s bins following a sequence of successive left- or right-alternative reinforcers that ended with a single disconfirmation in Conditions 9, 10, 11, and 12, respectively. Again, some data points have been omitted due to preference being exclusive to the alternative at which a reinforcer was just obtained. These figures show that there were no consistent changes in the log response ratios emitted after disconfirmations throughout a component. Moreover, they were smaller than the effects shown in Figures 3.24 to 3.27, both in terms of their initial magnitudes and their durations. To clarify these effects, Figure 3.33 plots the differences between the log response ratios emitted after a disconfirmation that followed sequences of same alternative reinforcers that varied in their length in Conditions 9 to 15. Figure 3.33 shows that the differences between the log response ratios emitted following a disconfirmation decreased as the preceding sequence of confirming reinforcers increased. The differences evident in the fourth, eighth, and sixteenth 2-s bins were very similar. Across conditions there were no discernable changes in these differences.
Figure 3.29. The log response ratios emitted in successive 2-s time bins in Condition 9 following sequences of successive same-alternative reinforcers that ended with a single "disconfirmation", and began at the start of a component.
Figure 3.30. The log response ratios emitted in successive 2-s time bins in Condition 10 following sequences of successive same-alternative reinforcers that ended with a single “disconfirmation”, and began at the start of a component.
Figure 3.31. The log response ratios emitted in successive 2-s time bins in Condition 11 following sequences of successive same-alternative reinforcers that ended with a single "disconfirmation", and began at the start of a component.
Figure 3.32. The log response ratios emitted in successive 2-s time bins in Condition 12 following sequences of successive same-alternative reinforcers that ended with a single "disconfirmation", and began at the start of a component.
Figure 3.33. The differences between the log response ratios emitted after "disconfirmations" which followed a sequences of successive left- or right-alternative confirming reinforcers plotted as a function of the sequential position of the reinforcer in a component for the first, second, fourth, eighth, and sixteenth 2-s bin following a reinforcer delivery in Conditions 9 to 15.
3.7.5 Response Rates

Figures 3.34 to 3.37 show the mean number of responses emitted in each 2-s bin following a reinforcer delivery for Conditions 9, 10, 11, and 12, respectively. These response rates are shown for specific sequences of the first six reinforcers obtained in a component: Either a sequence of reinforcers obtained at the same alternative; or, a sequence of reinforcers obtained at the same alternative followed by a disconfirmation. More variability was evident in response rates following the less frequently occurring sequences that ended with disconfirmations. In general, it was again the case that the response rate emitted following a right reinforcer was higher than that emitted following a left reinforcer irrespective of whether that reinforcer was obtained at the same alternative as the preceding reinforcer, or was a disconfirmation. Figures 3.35 to 3.37 show that in Conditions 10 to 12, the response rates emitted following a left-alternative disconfirmation were consistently low in the first one or two bins following a reinforcer delivery. However, this was not the case in Condition 9 (Figure 3.34), where no large decreases in response rate following a left-alternative reinforcer were evident.
Figure 3.34. The mean number of responses emitted in each successive 2-s bin following sequences one to six reinforcers in length that were successive confirmations or successive confirmations followed by a single disconfirmation in Condition 9.
Figure 3.35. The mean number of responses emitted in each successive 2-s bin following sequences one to six reinforcers in length that were successive confirmations or successive confirmations followed by a single disconfirmation in Condition 10.
Figure 3.36. The mean number of responses emitted in each successive 2-s bin following sequences one to six reinforcers in length that were successive confirmations or successive confirmations followed by a single disconfirmation in Condition 11.
Figure 3.37. The mean number of responses emitted in each successive 2-s bin following sequences one to six reinforcers in length that were successive confirmations or successive confirmations followed by a single disconfirmation in Condition 12.

3.8 Discussion

The present results replicated the main features of the results reported in Experiment 1a. The multiple linear regression analyses showed that control by the

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current-component reinforcer ratio rapidly increased with successive reinforcer deliveries. At the same time there was a rapid decrease in the control exerted by the previous-component reinforcer ratio.

The group data shown in Figure 3.22 suggested, and two-way repeated measures ANOVAs using data from the individual subjects supported, that there was an effect of the within-session variation arranged in the reinforcer ratios. Sensitivity to the current-component reinforcer ratio increased more quickly when less variation was arranged in the reinforcer ratios (i.e., Conditions 9 and 15). In contrast, the results with respect to sensitivity to the previous-component reinforcer ratio were less clear. In the replicated set of conditions (Conditions 12 to 15), control by the previous-component reinforcer ratio decreased more quickly when there was less variation in the reinforcer ratios (i.e., Condition 15). Although there was some evidence for this effect in Figure 3.22 for Conditions 9 to 12, the ANOVAs failed to support this.

Landon and Davison (2001) used repeated non-parametric tests for trend to assess these effects, and found mixed results. They suggested there might be an effect of variation in the reinforcer ratios, but no definitive conclusions could be made. The present analyses provide a little more evidence for such an effect, but again the evidence is equivocal. The suggested effect is one where control was more local in conditions where little variation was arranged in the within-session changes in reinforcer ratios.

Converging evidence for such an effect was provided by the reinforcer-by-reinforcer analyses (Figure 3.23). Specifically, disconfirmations had much larger effects on preference in the following inter-reinforcer interval in Conditions 9 and 15 (both 27:1 or 1:27), and to a lesser extent Conditions 10 and 14 (both 27:1, 27:1, 3:1,
1:3, 1:27, and 1:27). The arrangements in Conditions 9 and 15 meant that there was a high frequency of long sequences of successive reinforcers obtained at the same alternative (Figure 3.21). Despite this, a single reinforcer from the opposite alternative reversed preference in the next inter-reinforcer interval regardless of its sequential position in a component. In Conditions 10 and 14 these preference reversals occurred up to the fifth or sixth reinforcer in a component, whereas in the remaining conditions, and those in Experiment 1a, they ceased by the third or fourth reinforcer in a component. These results, like those from the multiple linear regressions, suggest that control was more local in conditions where less variation was arranged in the reinforcer ratios, or, as shown in Figures 3.16 and 3.21, where sequences of successive reinforcers obtained at the same alternative were more frequent.

The reasons for the preference reversals following disconfirmations in the tree diagrams (Figure 3.23) were not obvious in the analyses of behaviour during inter-reinforcer intervals (Figures 3.29 to 3.32). The latter figures showed that preferences were similar following disconfirmations in successive 2-s bins in Conditions 9 to 15. However, the analyses of response rates in these same bins did show a difference between Condition 9 (27:1 or 1:27), and Conditions 10 (27:1, 27:1, 3:1, 1:3, 1:27, and 1:27), 11 (27:1, 27:1, 3:1,, 1:1, 1:3, 1:27, and 1:27) and 12 (27:1 to 1:27). In Conditions 10 to 14, the response rates following a left-alternative disconfirmation were substantially lower soon after a reinforcer delivery than those emitted following the other two-reinforcer sequences. It is worth reiterating at this stage that the behaviour of all subjects was biased towards the right alternative. If Figure 3.23 is re-examined, it can be seen that, in general, a right-alternative disconfirmation moved preference further towards the right alternative than a left-alternative reinforcer did
towards the left alternative. This applies with the exception of Conditions 9 and 15, where the movements were similar in magnitude. Disconfirmations at the left alternative in Conditions 9 and 15 resulted in a log response ratio in the next inter-reinforcer interval that was close to 0 (mean = -0.04), whereas in other conditions this log response ratio was closer to -0.2 (mean = -0.18). The suggestion is that left-alternative disconfirmations resulted in smaller changes in preference in Conditions 10 to 14 because the response rate emitted when preference was most extreme (i.e., just after a reinforcer delivery) was low. In contrast, in Conditions 9 and 15, the extreme preference just after a reinforcer was coupled with a higher response rate. Thus, more extreme preferences were recorded in the next inter-reinforcer interval, and preference reversals were seen in Figure 3.23.

Across all conditions, the most frequently occurring sequences of reinforcers were those consisting of successive confirming reinforcers at either alternative. When behaviour was examined at a reinforcer-by-reinforcer level, these sequences of reinforcers resulted in more extreme preferences when their occurrence was more frequent (i.e., Conditions 9 and 15). At a more local level of analysis, this effect was seen in more extreme and longer transient movements in preference following a reinforcer delivery. In contrast, at a reinforcer-by-reinforcer level, disconfirmations had very large effects on preference, but with the exceptions of Conditions 9 and 15 as discussed above, were very similar in their absolute effects across conditions. As discussed in Experiment 1a, the large effects of disconfirmations appear to be due to the extremity of preference prior to their occurrence, as their effects are almost identical when viewed at a more local level. This further suggests that the important feature of the present experimental arrangement might be the frequency with which specific sequences of reinforcers occur.
3.9 *Experiment 1c*

Experiments 1a and 1b showed that when reinforcer ratios were changed very rapidly in a single session, clear effects of individual reinforcers were evident. However, there was evidence in both experiments that control was not solely local in nature. In Experiment 1a, control became more local as the range of reinforcer ratios was increased. Whereas, in Experiment 1b, control became more local as the variation in the reinforcer ratios was decreased and their range held constant. It remained, however, that the range of reinforcer ratios was relatively extreme (27:1 to 1:27). In both experiments, control became more local as the proportion of sequences arranging successive confirming reinforcers was increased.

The relevance of these results to more standard concurrent-schedule preparations remains questionable. One reason for this is the speed at which the reinforcer ratios changed in Experiments 1a and 1b. This issue remains open, although it should be noted that Condition 8 (all 1:1) of Experiment 1a was equivalent to a standard concurrent-schedule procedure with equal reinforcer ratios and a 10-s blackout after every tenth reinforcer. This finding suggests that the local effects of reinforcers may also be present in steady-state concurrent-schedule performance.

One feature that Conditions 1 to 16 had in common was that, in each case, a symmetrical distribution of reinforcer ratios was arranged. It is not clear at this stage what impact an asymmetrical distribution of reinforcer ratios would have on the local effects of reinforcers. Moreover, with the exception of when the reinforcer ratio is 1:1, standard steady-state concurrent schedules consist of unequal reinforcer ratios, or in the present context, asymmetrical distributions of reinforcers.
Experiment 1c explored the effects of various asymmetrical distributions of reinforcers using the same basic procedure as in Experiments 1a and 1b. Using the same logarithmic spacing as previously, the range of reinforcer ratios was 9:1 to 1:81 in Condition 17, and 81:1 to 1:9 in Condition 18. The latter was replicated in Conditions 19 and 20 with short (1-s) and long (120-s) blackouts between components. Thus, the range of reinforcer ratios was the same as in Conditions 1, 6, and 12, but the distribution was asymmetrical, and the reinforcer ratios became more extreme. Conditions 21 and 22 arranged reinforcer ratios of 27:1 to 1:27 with unequal reinforcer magnitude ratios. Conditions 23 and 24 arranged a symmetrical (in log terms) range of variation (1:27 to 1:2.37 and 27:1 to 2.37:1) distributed around 1:8 and 8:1, respectively. Finally, Conditions 25 to 28 arranged the same reinforcer ratios in all components (1:8, 8:1, 1:4, and 4:1 respectively). Thus, asymmetrical distributions were arranged with no variation in the reinforcer ratio, and the procedure became essentially equivalent to steady-state concurrent schedules.

3.10 Method

Subjects and Apparatus

The subjects and apparatus were identical to those used in Experiments 1a and 1b.

Procedure

The subjects were trained on the same basic procedure as used in Experiment 1a, and the sequence of experimental conditions is shown in Table 3.3. The procedure was altered for Conditions 19 to 22 in the following ways. In Conditions 19 and 20, the blackout between components was varied. In Condition 19, the blackout was 1 s, and in Condition 20 it was 120 s. The long blackouts arranged in
Condition 20 necessitated a change in session length for that condition. Thus, for Condition 20, sessions ended after the completion of the seven components (70 reinforcers), or after 60 min had elapsed, whichever occurred first.

In Conditions 21 and 22 the magnitude of reinforcement was made unequal, a 3:1 (L/R) ratio was arranged in Condition 21, and a 1:3 ratio in Condition 22. This was arranged as follows: For these conditions, reinforcers consisted of a specified number of successive 1.2-s hopper presentations. These presentations were separated by 0.5-s blackouts. Thus, in Condition 21, a left-alternative reinforcer consisted of six successive 1.2-s hopper presentations, and a right-alternative reinforcer consisted of two successive 1.2-s hopper presentations. These were reversed in Condition 22.

In Conditions 17 and 18 the range of reinforcer ratios was held constant (9:1 to 81:1 and 81:1 to 1:9, respectively). Conditions 19 and 20 used the same range of reinforcer ratios as Condition 18 (81:1 to 1:9), however the blackouts between components were 1 s and 120 s as described above. The range of reinforcer ratios arranged in Conditions 21 and 22 was constant at 27:1 to 1:27 and the ratio of reinforcer magnitudes was varied (3:1 and 1:3). For Conditions 23 and 24, the range was held constant (27:1 to 2.37:1 and 1:2.37 to 1:27), but this distribution was arranged around central reinforcer ratios of 1:8 and 8:1 respectively. Finally, in Conditions 25 to 28, each of the seven components in a session arranged the same reinforcer ratio (8:1, 1:8, 4:1, and 1:4 respectively).
Table 3.3
Sequence of experimental conditions and relative reinforcer probability (shown as probability of reinforcement on the left alternative) for each of the seven components in each condition in Experiment 1a. The overall probability of reinforcement per second was constant at .037 throughout. Unless stated otherwise (*), reinforcement consisted of 2.5-s access to wheat, and there was a 10-s blackout between components.

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3.11 Results

3.11.1 Multiple linear regression analyses

In conditions in which variation of the within-session changes in reinforcer ratios was arranged (i.e., Conditions 17 to 24), identical multiple linear regression analyses to those reported for Experiments la and lb were carried out. As previously, in each condition the numbers of responses emitted at each alternative were summed separately for each component in the periods before each successive reinforcer delivery. Equation 3.1 was then fit to the data. Figure 3.38 shows sensitivity to the current- and previous-component reinforcer ratios plotted as a function of successive reinforcer deliveries in a component.

In each condition, sensitivity to the previous-component reinforcer ratio started above zero (mean = 0.28, range, 0.11 to 0.52), this was also the case for each individual subject (mean = 0.30, range, 0.003 to 0.74). These values then fell towards zero with successive reinforcer deliveries. Across conditions, with the exceptions of Condition 19, 20, and 24, similar levels of control by the previous-component reinforcer ratio were evident. In Condition 19, when the blackout between components was 1 s, there was increased control by the previous-component reinforcer ratio at the start of the current component (group = 0.52, individuals ranged from 0.37 to 0.74). In contrast, in Condition 20 when the blackout between components was 120 s, there was reduced control by the previous-component reinforcer ratio (group = 0.15, individuals ranged from 0.09 to 0.24). These results are consistent with those reported by Davison and Baum (2002). However, in Condition 24 (range 27:1 to 2.37:1, centred at 8:1), there was also reduced control by the previous-component reinforcer ratio (group = 0.11, individuals ranged from 0.003 to 0.22).
Figure 3.38. Sensitivity to reinforcement values from multiple linear regressions between log response ratios and arranged log reinforcer ratios (Equation 3.1) in the previous and current components for each successive reinforcer delivery. Each panel represents data from a different condition in Experiment 1c. Response numbers were summed across all six subjects.
Prior to any reinforcers being obtained in a component, sensitivity to the current-component reinforcer ratio was close to zero (range, -0.04 to 0.01). Sensitivity to the current-component reinforcer ratio increased with successive reinforcer deliveries, and after nine reinforcer deliveries the mean sensitivity was 0.55 (range 0.34 to 0.78). This compares with mean sensitivities of 0.46 and 0.58, respectively, at the same point in Experiments 1a and 1b. As previously, the individual data showed the same general effects.

Although these data were very similar to those obtained in Experiments 1a and 1b, several differences were evident across conditions in Figure 3.38. First, when Conditions 17 to 20 are considered, it was evident that Conditions 17 and 18 provided data that were very similar. As outlined above, the variation in the blackout between components affected the initial sensitivity to the previous-component reinforcer ratio. With respect to sensitivity to the current-component reinforcer ratio, sensitivities reached much higher levels when the blackout was 120 s (Condition 20). In fact, these values were similar to those obtained in steady-state procedures (Taylor & Davison, 1983). In Conditions 23 and 24, sensitivities to the current-component reinforcer ratio were, in general, lower.

3.11.2 Reinforcer-by-reinforcer analyses

Figure 3.39 shows part of the tree structures derived from the reinforcer-by-reinforcer analyses as described earlier for Conditions 17 (9:1 to 1:81) and 18 to 20 (81:1 to 1:9, with 10, 1, and 120-s blackouts between components respectively). Several similarities between Figure 3.39 and the trees seen previously (Figures 3.4 and 3.23) are evident: Successive confirming reinforcers had diminishing effects on
preference; disconfirmations had comparatively very large effects on preference; and, disconfirmations early in a component resulted in reversals of preference.

Figure 3.39. Log response ratios emitted in inter-reinforcer intervals following successive same-alternative reinforcers (solid lines) in Conditions 17 to 20. The broken lines join "disconfirmations", where a reinforcer was obtained from the other alternative following sequences of successive same-alternative reinforcers.

In addition, several clear differences are evident between Figure 3.39 and Figures 3.4 and 3.23: First, preference prior to any reinforcer deliveries in a component was clearly influenced by the distribution of reinforcer ratios arranged – in Condition 17, the log response ratio emitted prior to any reinforcers being obtained was -0.45, whereas in Condition 18 it was -0.07. In Condition 19, in which the 1-s
blackout was arranged between components, preference prior to any reinforcers being obtained favoured the left alternative (0.08), as it did in Condition 20 (120-s blackout, 0.07). This latter finding is surprising given the longer blackout and lower level of control exerted by the previous-component reinforcer ratio. Perhaps more interesting is that the trees were, in all cases, asymmetrical. Preferences began somewhat biased towards the higher reinforcer-rate alternative (biased relative to where they began in Experiments 1a and 1b in which symmetrical distributions of reinforcer ratios were arranged). Thereafter, reinforcers at the higher reinforcer-rate alternative had smaller diminishing effects on subsequent preferences than reinforcers obtained at the other alternative.

This asymmetry is also seen in Figures 3.40 and 3.41 where the same data are plotted for Conditions 21 to 24, and Conditions 25 to 27, respectively. In Conditions 21 and 22 in which unequal reinforcer magnitudes were arranged, the tree structures as a whole were shifted towards the alternative at which the larger reinforcers were obtained. However, as with Conditions 17 to 20, the trees were also asymmetrical. Successive reinforcers obtained at the alternative providing larger reinforcers had smaller effects than those obtained at the other alternative. Disconfirmations had effects similar to those seen previously.
Figure 3.40. Log response ratios emitted in inter-reinforcer intervals following successive same-alternative reinforcers (solid lines) in Conditions 21 to 24. The broken lines join “disconfirmations”, where a reinforcer was obtained from the other alternative following sequences of successive same-alternative reinforcers.

In Conditions 23 and 24 the range of reinforcer ratios was the same (1:2.37 to 1:27 and 27:1 to 2.37:1), distributed around 1:8 and 8:1 respectively. Figure 3.40 shows the tree structures had moved towards the higher reinforcer-rate alternative. Successive reinforcers obtained at the right alternative in Condition 23, and the left alternative in Condition 24, had small effects on behaviour. These small effects suggested the possibility that there were limits to how far preference would move towards the higher reinforcer-rate alternative. Disconfirmations at the alternative
providing the smaller reinforcers consistently moved preference beyond the average preference emitted prior to any reinforcer deliveries in a component.

Figure 3.41. Log response ratios emitted in inter-reinforcer intervals following successive same-alternative reinforcers (solid lines) in Conditions 25 to 28. The broken lines join “disconfirmations”, where a reinforcer was obtained from the other alternative following sequences of successive same-alternative reinforcers.

In Conditions 25 to 28, all seven components in a session arranged the same reinforcer ratio. Thus, as with Condition 8 (Figure 3.4), these conditions were functionally equivalent to steady-state concurrent schedules with blackouts after every ten reinforcer deliveries. Figure 3.41 shows that individual reinforcers still had large and consistent effects on preference in these conditions. The trees structures were again asymmetrical and biased towards the higher reinforcer-rate alternative. These
movements in the tree structures were ordered in the same way as the reinforcer ratios. Successive reinforcers at the higher reinforcer-rate alternative had small effects on preference. In fact, Figure 3.41 again suggests that in each condition there may have been a limit on how far preference would move following successive reinforcers obtained at that alternative. Disconfirmations again had comparatively large effects on preference. In Conditions 25 and 28, disconfirmations at the lower reinforcer-rate alternative moved preference beyond the level emitted prior to a reinforcer delivery in a component; in Conditions 26 and 27 they moved preference to similar levels to those emitted prior to any reinforcer deliveries.

Comparisons of Conditions 23 (Figure 3.40) and 26 (Figure 3.41), and Conditions 24 (Figure 3.40) and 25 (Figure 3.41), show that these pairs of conditions yielded almost identical results at this level of analysis. Preferences were similar at the beginning of a component, and continued to be similar throughout a component following various specific sequences of reinforcers. These conditions had the same sessional reinforcer ratios (1:8 or 8:1), but differed in terms of the range of reinforcer ratios arranged within components.

3.11.3 Reinforcer Sequences

Given the similarity between performance in Conditions 23 and 26, and Conditions 24 and 25, and that Experiments 1a and 1b suggested sequences of successive confirming reinforcers were important, it is again useful to examine the proportion of sequences that were of those types in Experiment 1c. Figure 3.42 shows these data for Conditions 17, 18, 21, and 23 to 28. Conditions 19 and 20 are not shown as they consisted of the same distribution of reinforcer ratios as Condition 18. Likewise, Condition 22 is not shown, as it was the same as Condition 21.
Figure 3.42. The proportions of all sequences one to six reinforcers in length that consisted exclusively of successive reinforcers at one alternative, or successive reinforcers at one alternative followed by a single “disconfirmation” in Experiment 1c.
Conditions 17 (9:1 to 1:81) and 18 (81:1 to 1:9) resulted in a higher proportion of sequences of confirming reinforcers at the right and left alternatives respectively. These can be compared directly with Condition 21 (27:1 to 1:27), which, in terms of the reinforcer ratios arranged, was identical to the canonical arrangement (Conditions 1, 6, and 12). For instance, in Condition 17, 0.35 of all six-reinforcer sequences were six successive right reinforcers, and .10 were six successive left reinforcers. In Condition 21, these proportions were .21 and .22 respectively.

Conditions 23 (1:2.37 to 1:27) and 26 (1:8), and Conditions 24 (27:1 to 2.37:1) and 25 (8:1) resulted in very similar proportions of sequences of confirming reinforcers. Despite this, they differed in small, but systematic ways. Consider Conditions 24 and 25. Both conditions resulted in high proportions of components beginning with six successive left reinforcers (.48 and .50, respectively). This pattern was consistent throughout, with Condition 25 (8:1) providing a slightly higher proportion of these sequences. Other sequences occurred infrequently, and those that occurred more frequently contained a large proportion of left reinforcers, but few differences were evident across conditions (e.g., LLLLL LR, .06 in both conditions, and RLLLLL, .08 in both conditions).

3.11.4 Behaviour in inter-reinforcer intervals

Figures 3.43 to 3.50 show the log left/right response ratios emitted in successive 2-s time bins following sequences of successive reinforcers obtained at the same alternative for Conditions 18, 19, 20, 21, 22, 24, 25, and 27, respectively. As with this analysis carried out previously, in some cases responding in a time bin was exclusive to the alternative at which a reinforcer was just obtained, and thus occasional data points have been omitted. In most cases this occurred soon after a
reinforcer delivery as in previous conditions. However, in a few cases this occurred later in inter-reinforcer intervals. Data points have also been omitted when a particular time bin was reached on fewer than ten occasions. The results reported previously were replicated here. Specifically, within conditions, with successive reinforcers obtained at the same alternative, the resulting changes in preference became both more extreme and longer in duration.

Figures 3.43 to 3.45 (Conditions 18 to 20) can be directly compared, as they consisted of the same component reinforcer ratios (81:1 to 1:9) with the blackout between components varied (10, 1, and 120 s respectively). Conditions 18 and 19 (10- and 1-s blackouts) provided very similar results. When compared to the canonical condition (Condition 12: Figure 3.27), behaviour following a reinforcer at either alternative was more biased towards the right alternative than when a symmetrical distribution of reinforcer ratios was arranged. Condition 20 (Figure 3.45: 120-s blackout) differed only in that behaviour was, in general, slightly more extreme than that evident in Conditions 18 and 19.
Figure 3.43. The log response ratios emitted in successive 2-s time bins in Condition 18 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.44. The log response ratios emitted in successive 2-s time bins in Condition 19 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.45. The log response ratios emitted in successive 2-s time bins in Condition 20 following sequences of successive same-alternative reinforcers that began at the start of a component.

Figures 3.46 and 3.47 show the equivalent analyses using Conditions 21 and 22 where the canonical distribution of reinforcer ratios was arranged with 3:1 and 1:3 reinforcer magnitude ratios respectively. Figure 3.46 (Condition 21) shows that behaviour was more biased towards the left alternative than when the canonical
procedure was arranged with equal reinforcer magnitudes (Condition 12: Figure 3.27). The transient movements in preference following a reinforcer at the left alternative (the larger reinforcers) were also longer than seen previously. After the first left reinforcer in a component, preference did not approach stable levels until about the thirteenth 2-s bin after the reinforcer delivery. Both the extremity and the duration of these movements in preference increased with successive left reinforcers. A right reinforcer had much briefer effects on preference, both when compared to the effects of a left reinforcer in Condition 21, and a right reinforcer in Condition 12. Preference approached a stable level by about the sixth 2-s bin following a single right reinforcer in Figure 3.46, as opposed to the thirteenth bin for a left reinforcer, and about the ninth or tenth bin in Condition 12 (Figure 3.27).
Figure 3.46. The log response ratios emitted in successive 2-s time bins in Condition 21 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.47. The log response ratios emitted in successive 2-s time bins in Condition 22 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.48. The log response ratios emitted in successive 2-s time bins in Condition 24 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.49. The log response ratios emitted in successive 2-s time bins in Condition 25 following sequences of successive same-alternative reinforcers that began at the start of a component.
Figure 3.50. The log response ratios emitted in successive 2-s time bins in Condition 27 following sequences of successive same-alternative reinforcers that began at the start of a component.

Figures 3.48 to 3.50 show the equivalent data from Conditions 24, 25, and 27, respectively. In these conditions the distributions of reinforcers were asymmetrical to the extent that the left alternative always provided more frequent reinforcers. Thus, long sequences of right reinforcers were very infrequent (see Figure 3.42), and data
have been omitted from Figures 3.48 to 3.50 when the particular time bin was not reached on 10 occasions.

Figures 3.48 and 3.49 show that, as with the reinforcer-by-reinforcer analyses, Conditions 24 (27:1 to 2.37:1, centre 8:1) and 25 (all 8:1) provided almost identical results. The transient movements in preference following a reinforcer at the left alternative were longer than those seen in previous conditions, and the stable levels of behaviour further into the inter-reinforcer interval shifted towards the higher reinforcer-rate left alternative. The transient movements in preference increased in duration with successive confirming reinforcers as in prior conditions. Reinforcers at the lower reinforcer-rate right alternative had comparatively brief effects on preference, with preference close to its stable levels by about the fifth 2-s bin after a reinforcer delivery. When Condition 27 (all 4:1, Figure 3.50) is compared, the same effects are evident. The only differences were that the transient movements in preference were slightly shorter in duration, and the stable levels of behaviour were slightly less extreme reflecting the less extreme reinforcer ratios arranged.

Figures 3.43 to 3.45 showed few differences in the behaviour emitted in inter-reinforcer intervals following sequences of confirming reinforcers across Conditions 18 to 20 (81:1 to 1:9 with 10-s, 1-s, and 120-s blackouts, respectively). The similarities were even greater when behaviour following sequences of successive confirming reinforcers that ended with a single disconfirmation were examined. As shown above (Figure 3.42), these sequences occurred much less frequently. Figure 3.51 shows the log response ratios emitted following these sequences of reinforcers for Condition 18 (10-s blackout). Conditions 19 (1-s blackout) and 20 (120-s blackout) are not shown, as again they were virtually identical. Immediately following a reinforcer delivery, there was a large transient shift in preference towards
the alternative at which the reinforcer was just obtained. By between the third and fifth 2-s bin after a reinforcer delivery, preferences had reached similar levels that were biased towards the left alternative when compared to results from the canonical condition (Condition 12: Figure 3.32). The transient movements in preference were also larger towards the left (higher reinforcer-rate) alternative; this was due, at least in part, to the generally lower response rates evident after a left-alternative reinforcer.

Figures 3.52 and 3.53 show the same analyses for Conditions 21 (27:1 to 1:27, 3:1 reinforcer magnitude ratio) and 22 (27:1 to 1:27, 1:3 reinforcer magnitude ratio). Across the two conditions, the stable levels of responding after the transient movements in preference had dissipated were biased towards the alternative at which the larger reinforcers were obtained. The transient movements in preference following a small reinforcer were similar to those seen in previous conditions: They were brief, and preference returned quickly (approximately three to five 2-s bins) to a level approximating indifference. However, disconfirmations obtained at the alternative providing the larger reinforcers resulted in transient movements in preference that were longer in duration than those following a reinforcer at the other alternative (about eleven 2-s bins). Moreover, in Condition 22, in which the larger reinforcers were provided for responses to the right alternative, towards which the behaviour of all subjects was biased, behaviour was exclusive to the right alternative following a disconfirming reinforcer at the right alternative in the first five or six 2-s bins following a reinforcer delivery.
CONDITION 18 (81:1 TO 1:9)

L OR R

RL OR LR

RRL OR LLR

RRRL OR LLLR

RRRRL OR LLLLLR

TIME SINCE REINFORCEMENT (2-s BINS)

Figure 3.51. The log response ratios emitted in successive 2-s time bins in Condition 18 following sequences of successive same-alternative reinforcers that ended with a single "disconfirmation", and began at the start of a component.
Figure 3.52. The log response ratios emitted in successive 2-s time bins in Condition 21 following sequences of successive same-alternative reinforcers that ended with a single "disconfirmation", and began at the start of a component.
Figure 3.53. The log response ratios emitted in successive 2-s time bins in Condition 22 following sequences of successive same-alternative reinforcers that ended with a single “disconfirmation”, and began at the start of a component.
Figure 3.54. The log response ratios emitted in successive 2-s time bins in Condition 23 following sequences of successive same-alternative reinforcers that ended with a single “disconfirmation”, and began at the start of a component.
Figure 3.55. The log response ratios emitted in successive 2-s time bins in Condition 26 following sequences of successive same-alternative reinforcers that ended with a single “disconfirmation”, and began at the start of a component.
Figure 3.56. The log response ratios emitted in successive 2-s time bins in Condition 28 following sequences of successive same-alternative reinforcers that ended with a single “disconfirmation”, and began at the start of a component.

Figures 3.54 to 3.56 show the same data for Conditions 23 (1:2.37 to 1:27, centre 1:8), 26 (all 1:8), and 28 (all 1:4). Given the reinforcer ratios arranged in these conditions, some sequences of reinforcers did not occur, specifically sequences of successive left reinforcers followed by a disconfirming right reinforcer. Across these
three conditions, virtually identical results were found. Overall, preference was biased towards the higher reinforcer-rate right alternative. A left-alternative disconfirmation resulted in a very brief transient movement in preference towards the left alternative (just the first 2-s bin). By the second 2-s bin, preference had reached the stable levels evident later in the inter-reinforcer interval. However, preference continued to move towards the right alternative beyond the apparent stable levels of preference for a period, and returned to the stable levels by about the eleventh 2-s bin after the reinforcer delivery.

3.12 Discussion

Experiment 1c differed from Experiments 1a and 1b in that a variety of asymmetrical distributions of reinforcers were arranged. Reinforcer ratio distributions were arranged that were centred at reinforcer ratios other than 1:1, and in Conditions 21 and 22 the canonical distribution of reinforcer ratios (27:1 to 1:27) was arranged with unequal reinforcer magnitudes. In all these conditions, the strong local effects of reinforcers shown previously were evident as in the previous experiments. The manipulations made did, however, result in regular changes in performance across conditions.

Multiple linear regression analyses showed results that were consistent with the earlier experiments. In Conditions 21 and 22 (Figure 3.38, 27:1 to 1:27, with 3:1 and 1:3 reinforcer magnitude ratios respectively), the results were almost identical to those obtained earlier with the same reinforcer ratio distribution and equal reinforcer magnitudes (Condition 12, Figure 3.22). Similar results were also obtained in Conditions 17 and 18 (9:1 to 1:81, and 81:12 to 1:9, respectively).
In Conditions 19 and 20, the same range of reinforcer ratios as in Condition 18 was arranged with blackouts between components of 1 and 120 s. Sensitivity to the previous-component reinforcer ratio increased as the blackout between components was reduced, and sensitivity to the current-component reinforcer ratio reached higher levels in Condition 20 when the blackout was very long. A more extensive investigation of the effects of the blackout between components has been reported elsewhere (Davison & Baum, 2002) using symmetrical distributions of reinforcer ratios. They reported similar results, and the present results add some generality in terms of the symmetry of the distributions of reinforcer ratios arranged. These specific results are, in general, consistent with the accumulator model proposed by Davison and Baum (2000, but see Landon and Davison, 2001, Davison and Baum, 2002, and later). The model proposes that reinforcers are lost from the accumulations with the passage of time; thus, when the blackout is very short, events in the previous component should have a greater effect on current performance, and likewise when the blackout is very long, prior events will have less influence and behaviour will change faster.

Conditions 23 (1:2.37 to 1:27, centre at 1:8) and 24 (27:1 to 2.37:1, centre at 8:1) provided lower values of sensitivity to the current-component reinforcer ratio than the other conditions in the present experiment. This can be attributed to the range of reinforcer ratios arranged in those two conditions. Conditions 23 and 24 consisted of the same range of reinforcer ratios as Condition 5 of Experiment 1a (3.38:1 to 1:3.38). This range was then shifted so that it was centred at 1:8 (Condition 23) and 8:1 (Condition 24). Thus, the range of reinforcer ratios arranged in Conditions 23 and 24 was smaller than the other conditions in Experiment 1c.

Experiment 1a showed that the range of reinforcer ratios arranged had an effect on the
sensitivity values obtained. Thus, smaller values of current-component sensitivity might have been expected in Conditions 23 and 24. Moreover, if the equivalent analyses for Condition 5 are revisited (Figure 3.3), it is clear that the sensitivity values obtained in Conditions 23 and 24 are very similar to those obtained in Condition 5.

The reinforcer-by-reinforcer analyses replicated the main effects seen previously: Specifically, successive confirming reinforcers had diminishing effects on behaviour, and disconfirmations had comparatively large effects. The reasons for this have been discussed previously. When asymmetrical distributions of reinforcer ratios were arranged, two obvious changes occurred in the tree structures: First, the tree structures as a whole moved towards the higher reinforcer-rate alternative; and second, the tree structures themselves became noticeably asymmetrical with reinforcers obtained at the higher reinforcer-rate alternative having very small diminishing effects on subsequent behaviour. The shift in the trees suggests either an effect of carryover, or some control by the molar reinforcer ratio. When the blackout duration was varied, the shifts in preference were not as systematic as might be expected if they were due entirely to carryover. Thus, the latter is the option favoured here. As mentioned in the results, these diminishing effects suggest limits to how far preference would move in response to specific sequences of reinforcers. These limits were ordered in the same way as the central reinforcer ratios (Conditions 17 to 20, 23 and 24) or the only reinforcer ratios arranged (Conditions 25 to 28), or, as seen in Figure 3.42, the proportion of sequences of reinforcers that were obtained exclusively at that alternative.

These effects must arise from the changes seen in behaviour during inter-reinforcer intervals. When the behaviour in inter-reinforcer intervals following sequences of confirming reinforcers in Condition 25 (all 8:1: Figure 3.49) is
compared with behaviour following those same sequences in the canonical procedure (Condition 12: Figure 3.27), several differences are evident: First, the transient changes in preference following a reinforcer delivery are longer in duration in Condition 25, especially early in a component (i.e., first three reinforcers). For example, following two left reinforcers in Condition 25 behaviour was still approaching stable levels after sixteen 2-s bins, whereas behaviour was reasonably stable by the seventh 2-s bin following the same sequence of reinforcers in Condition 12. Moreover, early in a component, these stable levels appeared to be more extreme in Condition 25. This was not the case by the fifth or sixth reinforcer in a component, although preference remained more extreme for longer in Condition 25.

Where Figures 3.39, 3.40, and 3.41 show the behavioural effects of sequences of successive reinforcers obtained at the higher reinforcer-rate alternative, the log response ratios would have consisted largely of behaviour from the transient movements in preference shown in Figures 3.43 to 3.50 where preferences were relatively extreme. As has been shown, the durations of these transient movements in preference changed, both within Experiment 1c, and across all three experiments. As these durations increased, the log response ratios emitted in the whole inter-reinforcer intervals would also have changed, becoming more extreme as the durations increased. In Experiment 1c, this was particularly noticeable early in a component, where, compared to when symmetrical distributions of reinforcers were arranged, the transient movements in preference were very long in duration. Hence, when examined at a reinforcer-by-reinforcer level, successive confirming reinforcers appeared to have small diminishing effects. In reality, their effects were large and consistent. Behaviour early in a component began closer to the apparent limit that it could reach in a condition, and the small differences in the durations of the transient
movements in preference across conditions resulted in changes in these apparent limits to preference.

Conditions 21 (27:1 to 1:27, 3:1 reinforcer magnitude ratio) and 21 (27:1 to 1:27, 1:3 reinforcer magnitude ratio), in which unequal reinforcer magnitudes were arranged, produced results that were commensurate with the above treatment of asymmetrical reinforcer-ratio distributions. The transient movements in preference following a large reinforcer were longer than those seen when symmetrical reinforcer distributions were arranged, and increased with successive reinforcers obtained at that alternative. At a reinforcer-by-reinforcer level, preference began closer to indifference than in comparable conditions with asymmetrical reinforcer ratio distributions, despite performance in inter-reinforcer intervals being somewhat similar. The most obvious reason for this is the symmetrical distribution of reinforcer ratios arranged, meaning long sequences of small reinforcers were equally as likely as long sequences of larger reinforcers. Whether the effects of the range of reinforcer ratios and reinforcer magnitude are independent, or interact in some way, is a question that must be addressed by a more thorough empirical investigation than was undertaken here. Nevertheless, the present results suggest that asymmetrical distributions of reinforcer ratios, and differences in reinforcer magnitudes have similar effects.

To summarise, the local effects of individual reinforcers seen in Experiments 1a and 1b, and first reported by Davison and Baum (2000), were replicated. When symmetrical distributions of reinforcers were arranged, asymmetrical effects of reinforcers were also evident. Tree structures constructed from behaviour emitted following each successive reinforcer shifted towards the higher reinforcer-rate alternative, and became asymmetrical themselves. When just one component
reinforcer ratio was arranged, apparent limits to how extreme behaviour could become were apparent across conditions, and changed as a function of the reinforcer ratio arranged. These effects were understandable when the behaviour emitted during inter-reinforcer intervals was examined.

3.13 General Discussion

The three experiments reported here replicate and extend the results initially reported by Davison and Baum (2000). In a variety of conditions, local effects of individual reinforcers were evident that were similar in nature to those reported by Davison and Baum. Data from the present experiments were analysed at a number of different levels, and regularities were evident at each level of analysis.

Experiment 1a showed that the effects of individual reinforcers in the present procedure were modified by the context in which they were obtained. Sensitivity reached higher levels, carryover between components was greater, and individual reinforcers had larger effects when the range of reinforcer ratios arranged was greater. At this stage it is worthwhile revisiting the accumulator model proposed by Davison and Baum (2000). When this model is considered in the context of the data from Experiment 1a, it can predict the major features of the data, but not with a single set of parameter values. The simplest way for the model to predict the context effect found was for the arranged-extraneous discriminability parameter \( p_e \) to vary inversely with the range of reinforcer ratios arranged. Thus, in a condition in which a small range of reinforcer ratios was arranged this parameter would need to be large, so that few reinforcers would be lost from the accumulations. With the accumulations remaining high, individual reinforcers would have smaller effects and sensitivities remain lower.
Obviously it would be preferable for the model to account for all findings with a single set of parameter values. The modification described above is similar to a long memory window in the common model (Dow & Lea, 1987), and makes the Davison and Baum model, in such conditions, more similar to the cumulative-effects model (Davis et al., 1993). Although this approach seems intuitively reasonable, there is a lack of converging evidence supporting such a modification. Moreover, given the changes in the particular sequences of reinforcers seen in Experiment 1a, it would be equally plausible to suggest that this discriminability parameter should be higher in conditions where a larger range of reinforcer ratios was arranged and sequences of successive confirming reinforcers were very common. Given the problems this model has, and the others outlined also have, it seems, at this stage, that the best approach is to put aside attempts to model the data and concentrate on the features of the data themselves.

The present experiments provide evidence at a number of different levels of analysis of strong local effects of individual reinforcers on behaviour. Across both experiments evidence has been provided for both local and molar control over choice responding. The data from Experiment 1a suggest that molar control increased as the range of within-session changes in reinforcer ratios was decreased. The data from Experiment 1b suggest that this molar control decreased as increased variation was arranged in the within-session changes while holding the range constant. In Experiment 1c, the movements of the tree structures, and behaviour during inter-reinforcer intervals, towards the higher reinforcer-rate alternative provided some evidence of control by the molar reinforcer ratio. These results suggest the best way to view performance under these conditions might be in terms of dual, interacting,
control by local and more molar contingencies (Landon & Davison, 2001; see also Davis & Staddon, 1990).

It was also the case that across the experiments control became more local when the frequency of long sequences of confirming reinforcers increased. Another way of viewing performance in these conditions is more molar in nature. In the conditions where control was shown to be more local, it was also the case that a reinforcer at one alternative could have served as a discriminative stimulus for further responses at that alternative being reinforced. Cruse, Vitulli, and Dertke (1966) have shown that reinforcers of different types could function as discriminative stimuli in multiple schedules. In the literature on punishment, studies have shown that a punishing stimulus can act as a discriminative stimulus for future punishment (Dinsmoor, 1952), the absence of future reinforcement (Holz & Azrin, 1631), and the presence of future reinforcement (Holz & Azrin, 1961). The existence of similar effects with respect to reinforcers seems plausible. While no evidence directly supporting this type of interpretation has been presented here, it remains an alternative worthy of future investigation.

Experiments 1b and 1c showed that behaviour became more extreme when the same range of reinforcer ratios was arranged with less variation in the component reinforcer ratios (Experiment 1b), and when even more extreme reinforcer ratios were arranged in some components (Experiment 1c). When asymmetrical distributions of reinforcer ratios were arranged there was a general shift in behaviour towards the higher reinforcer-rate alternative. Analyses of the occurrence of specific sequences of reinforcers showed that as the range of reinforcer ratios arranged varied from always being 1:1, the most frequently occurring sequences consisted of successive confirming reinforcers. Moreover, when those sequences were very frequent
apparent limits to how far preference would move in response to a
given sequence appeared. These limits were ordered in the same way as the
reinforcer ratios arranged, and the relative frequency of the sequences themselves.

Across all conditions, when the data were examined at a reinforcer-by-
reinforcer level, disconfirming reinforcers had comparatively large effects on
behaviour. Analyses of behaviour in inter-reinforcer intervals showed that these
effects were similar across conditions in that they returned preference to a level
apparently representative of the molar reinforcer ratio. In Experiments 1a and 1b this
was a biased measure of indifference, and in Experiment 1c the level depended on
which alternative was favoured by the asymmetrical distribution of reinforcer ratios.
Thus, it seems that disconfirming reinforcers somehow re-set or deleted the effects of
previous reinforcers in that component. This interpretation is supported by the
analysis shown in Figure 3.5 where sequences of confirming reinforcers following a
disconfirmation moved preference to very similar levels as the same sequence
obtained at the beginning of a component (see also Killeen & Smith, 1984).

Much evidence, including the regularities discussed in the preceding
paragraphs and the effects of disconfirmations, suggests an important role of
sequences of successive confirming reinforcers. These sequences moved behaviour
towards the alternative at which the reinforcers were obtained, and a single
disconfirming reinforcer apparently erased their effects. Across all three experiments,
such sequences resulted in preferences that differed in terms of their extremity.
Another way to examine these preferences is in terms of how they differed as a
function of how frequently the sequences of confirming reinforcers occurred across
conditions.
Thus, across all conditions from the three experiments, except Conditions 21 and 22 in which reinforcer magnitude was varied, sequences of between two and six reinforcers in length from the beginning of a component were collated. The proportions of these sequences that were solely successive left- or right-alternative confirmations were then calculated \((p)\). The log response ratios emitted in the inter-reinforcer intervals following sequences of confirmations were then plotted as a function of the logistic transformations of these proportions \((p/(1-p))\), and are shown in Figure 3.57. Figure 3.57 shows again that more extreme preferences occurred following the same sequence of reinforcers when that sequence of reinforcers occurred more frequently. This relationship was negatively accelerating, orderly and similar irrespective of sequence length, range of reinforcer ratios, variation arranged in component reinforcer ratios, and the symmetry of the reinforcer ratio distributions.

As a whole, the present experiments suggest that the variables controlling behaviour operate at a number of levels. At one level, individual reinforcers have a clear effect on the subsequently emitted behaviour. At another, successive confirming reinforcers have increasing or cumulative effects; that is, the transient change in preference following the third successive left reinforcer is greater than that seen after the second such reinforcer. At yet another level, when such sequences occur with relatively greater frequency, these effects are again increased or cumulative. Finally, disconfirmations have comparatively very large effects and return preference quickly to a level reflecting the molar reinforcer ratio arranged in that condition.
Figure 3.57. Log response ratios emitted in inter-reinforcer intervals following sequences of successive same-alternative reinforcers that began at the start of a component, plotted as a function of the logistic transformations of the proportions of all sequences that length that were of that type \( p/(1-p) \).
Chapter IV

4.1 Experiment 2a

Behaviour in standard steady-state concurrent schedules is described well by the GML (Equations 1.2 and 1.3; Baum, 1974). Davison and McCarthy (1988) reviewed choice research and showed the GML had excellent generality across a wide range of choice situations that varied in terms of factors such as the types of schedules in operation, the stimulus arrangements, and the species studied. The GML, however, does not make any statement about the level at which the variables controlling choice behaviour operate. It has, nonetheless, led to the commonly held assumption that choice behaviour is controlled by relatively large aggregations of reinforcers.

More recently some researchers have focused on choice behaviour in environments that vary in terms of their stability (see Chapter 2). Some of the most recent studies have shown that in environments that change very rapidly (after every ten or so reinforcer deliveries), individual reinforcers have reliable and predictable effects on behaviour (e.g., Davison & Baum, 2000; 2002; Landon & Davison, 2001; and Chapter 3 of the present thesis). These data were also described well using more molar analyses based on the GML. Thus, regularities were evident at both local, and more molar, levels of analysis.

The implications of findings from procedures using frequently changing reinforcer ratios for more standard concurrent-schedule preparations are not yet clear. It is possible that the local effects of reinforcers evident when contingencies change very rapidly represent an extreme form of control brought about by rapid changes in the contingencies. If this were the case, such local effects of reinforcers might not be evident in steady-state concurrent VI VI performance. Instead, behavioural control might result from long-term aggregations of reinforcers. Alternatively, it might be
that similar local effects of reinforcers are present in steady-state concurrent VI VI performance and have not been detected because the relevant detailed data have not been collected and analysed. If the latter is true, it is possible that steady-state performance may arise from local effects, or it might arise from a combination of local effects and more long-term effects of aggregations of reinforcers.

To address these questions, a conventional switching-key concurrent VI VI experiment was arranged. Across eight conditions, the distribution of reinforcer ratios (27:1, 9:1, 3:1, 1:1, 1:3, 1:9, and 1:27) arranged within a single session by Davison and Baum (2000) were replicated. Each condition was in effect for 65 sessions, and the data from the last 50 sessions of each condition were used in the analyses. This is well in excess of the number of sessions usually conducted in each condition of a concurrent-schedule experiment (e.g., Hollard & Davison, 1971; Hunter & Davison, 1978; Stubbs, & Pliskoff, 1969). This ensured both that steady-state data were collected, and that sufficient data were collected to allow analyses at a local level.

4.2 Method

Subjects

The subjects were five homing pigeons numbered 131, 132, 134, 135, and 136. Another bird, numbered 133, died during the present experiment, and no data obtained from that subject have been included here. The subjects were maintained at 85% ± 15 g of their free-feeding body weights by post-session feeding of appropriate amounts of mixed grain. Water and grit were freely available to the subjects at all times.
Apparatus

Each bird was housed in a cage 380 mm high, 380 mm wide, and 380 mm deep. The back, left, and right walls of each cage were constructed of sheet metal, while the top, floor, and front wall consisted of metal bars. Each cage contained two wooden perches, the first mounted 95 mm from, and parallel to, the front wall, and the second mounted 95 mm from, and parallel to, the right wall.

The right wall of each cage contained three translucent response keys, 20 mm in diameter, centred 100 mm apart, and 200 mm above the perches. The centre key remained dark and inoperative throughout. The left key could be lit yellow, and the right key could be lit either red or green. Both keys, when lit, could be operated by pecks exceeding a force of approximately 0.1 N. A hopper containing wheat was located behind a 50-mm by 50-mm aperture situated 145 mm below the centre key. During reinforcer delivery, the hopper was raised to the aperture and illuminated for 4 s and the key lights were extinguished. All experimental events were arranged on an IBM®-PC compatible computer running MED-PC® software, in a room remote from the experimental cages. The computer recorded the time, at 10-ms resolution, at which every event occurred in experimental sessions.

Procedure

A standard switching-key (Findley, 1958) concurrent-schedule procedure was used. Sessions began with the left (switching) key lit yellow, and the right (main) key lit either red or green with equal probability. Reinforcers were scheduled according to a single exponential VI 30-s schedule \( p = .033/s \). Once a reinforcer was arranged, it was allocated to either the red or green alternative according to the probability for each condition, as shown in Table 4.1. Reinforcers were dependently scheduled (Stubbs & Pliskoff, 1969), meaning that once a reinforcer was arranged for one
alternative, no further reinforcers were arranged until that reinforcer had been obtained. A 2-s changeover delay (Herrnstein, 1961) prevented responses from producing an arranged reinforcer until 2 s had elapsed since the last switching-key response.

Table 4.1
Sequence of experimental conditions, relative reinforcer probability (shown as probability of reinforcement on the red alternative), and the reinforcer ratio for each of the eight conditions in Experiment 2a. The overall probability of reinforcement per second was constant at .033 throughout.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Relative reinforcer probability $p(R)$</th>
<th>Reinforcer ratio (R:G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.5000</td>
<td>1:1</td>
</tr>
<tr>
<td>2</td>
<td>.9643</td>
<td>27:1</td>
</tr>
<tr>
<td>3</td>
<td>.2500</td>
<td>1:3</td>
</tr>
<tr>
<td>4</td>
<td>.9000</td>
<td>9:1</td>
</tr>
<tr>
<td>5</td>
<td>.1000</td>
<td>1:9</td>
</tr>
<tr>
<td>6</td>
<td>.7500</td>
<td>3:1</td>
</tr>
<tr>
<td>7</td>
<td>.0357</td>
<td>1:27</td>
</tr>
<tr>
<td>8</td>
<td>.2500</td>
<td>1:3</td>
</tr>
</tbody>
</table>
The sequence of experimental conditions is shown in Table 4.1. Across conditions, the overall rate of reinforcement was constant, and the red/green reinforcer ratio was varied between 1:27 and 27:1 through seven equally logarithmically spaced levels. Condition 8 replicated Condition 3. No stability criterion was in effect. However, 65 sessions were conducted for each condition to ensure sufficient data were collected to allow analysis of particular sequences of reinforcers. The data from the last 50 sessions of each condition were used in the analyses. Sessions were conducted daily, and ended in blackout after 80 reinforcers had been obtained, or after 42 min had elapsed, whichever occurred first.

4.3 Results

4.3.1 Generalized matching

Figure 4.1 shows the logs of the red over green response- and time-allocation ratios plotted as a function of the logs of the red over green obtained reinforcer ratios for each subject. The unfilled symbols show data from Condition 8, which was a replication of Condition 3. The data from Condition 8 closely approximated those from Condition 3.

Figure 4.1 also shows the best fitting straight lines obtained by least squares linear regression of Equation 1.2 to the obtained data from Conditions 1 to 7. The equations for the fitted lines are shown on each panel, with the percentage of variance accounted for by the fitted lines. In all cases the lines described the data well with high percentages of variance accounted for. The biases evident in the behaviour of all subjects were small, and unsystematic. Sensitivity to reinforcement ranged from 0.87 to 1.10 (mean = 0.97) for response allocation measures. With the exception of Bird 135, these slopes were all in the range commonly found in such procedures (Taylor &
Davison, 1983). Time allocation sensitivities ranged from 1.04 to 1.29 (mean = 1.17), and were therefore slightly higher than, but were all within two standard deviations of, the mean value in such procedures (Taylor & Davison, 1983). The time measures of sensitivity to reinforcement were also higher than corresponding response measures, as is commonly the case (Taylor & Davison, 1983).
Figure 4.1 Log response- or time-allocation ratios plotted as a function of the log obtained reinforcer ratios for each subject in each condition of Experiment 2a. The straight lines were fitted using least squares linear regression, and the equations for each line are shown on the graphs.
4.3.2 Current preference and previous reinforcers

The contribution of recent reinforcers to current preference was examined as follows. First, for consistency with Davison and Baum (2000) and Landon and Davison (2001), a moving window of the eight most recently obtained reinforcers was used. Therefore, 256 distinct sequences of red and green reinforcers were in that window. Beginning with the eighth reinforcer in a session, red and green response numbers after each successive reinforcer were aggregated according to which of those 256 sequences in the last eight reinforcers they followed, and a log red/green response ratio calculated as a measure of current preference.

Not every sequence occurred in every condition. For example, Condition 7 arranged a red/green reinforcer ratio of 1:27. Sequences of eight successive red-alternative reinforcers were therefore very unlikely, and in fact did not occur in the 50 sessions analysed for Condition 7. Also, in a number of cases, no responses were emitted on one or other alternative after some sequences. It was not, therefore, possible to calculate a log response ratio for every reinforcer sequence in every condition.

For those sequences of reinforcers that did occur, and for which a log response ratio could be calculated, the contribution of each of the preceding eight reinforcers to the current log response ratio was measured by means of the following general linear model:

\[
\log \left( \frac{B_R}{B_G} \right) = \log k + \sum_{j=0}^{7} \left\{ R_j = R : b_j + R_j = G : -b_j \right\},
\]  

(4.1)

In Equation 4.1, the subscript \(j\) denotes reinforcer lags in the preceding sequence of eight reinforcers, so that \(R_0\) is the most recent reinforcer. The coefficients \(b_j\) are log (base 10) response ratios, and represent the amount of current preference attributable
to the reinforcer at Lag $j$. If that reinforcer was obtained at the red alternative, $b_j$ was added, because the log response ratio should have moved in a positive direction. In the same way, $b_j$ was subtracted if the reinforcer at Lag $j$ was obtained at the green alternative. The coefficient $b_j$ is termed log reinforcer effect. It is conceptually, but not quantitatively, analogous to sensitivity to reinforcement ($a$ in Equation 1.2) at each lag. The constant log $k$ is also a log response ratio, and measures the residual amount of current preference not attributable to any of the eight most recently obtained reinforcers.

The best-fitting least-squares estimates of $b_j$ and log $k$ were obtained by fitting Equation 4.1 to the log response ratios following each eight-reinforcer sequence using Quattro Pro® v. 8's Optimizer function. This analysis was carried out separately for each condition and for each subject. Figure 4.2 shows the results of these analyses. The log reinforcer effect ($b_j$) of each of the preceding reinforcers is plotted as a function of reinforcer lag (Lag 0 is the most recent reinforcer) for each subject and each condition. The constant (log $k$) is also shown for each subject and condition.

Figure 4.2 shows four major effects: First, the most recently obtained reinforcer had by far the largest effect on current behaviour; second, in each condition, reinforcers beyond lag zero had similar effects on current behaviour; third, reinforcers had larger effects on behaviour in conditions where the reinforcer ratio was more extreme; fourth, the constant (log $k$) was generally more extreme when the reinforcer ratios were more extreme.
Figure 4.2 Log reinforcer effect for each of the previous eight reinforcers plotted as a function of reinforcer lag (0 being the most recently obtained reinforcer) for each subject in Experiment 2a. Also shown are values of log $k$ (see Equation 4.1) for each subject.
The results in the original Condition 3 and its replication (Condition 8) shown in Figure 4.2 were very similar. This being the case, the data from Condition 3 were used in subsequent analyses, rather than those from Condition 8. A two-way repeated-measures ANOVA was used to confirm the effects of the reinforcer ratio and of the sequential position of the reinforcer on the log reinforcer effect. The ANOVA showed a significant effect of the reinforcer ratio \((F_{5,168} = 21.69, p < .05)\), but no significant effect of the sequential position of the reinforcer \((F_{6,168} = 1.98, p > .05)\).

The effect of the reinforcer ratios on log reinforcer effect was investigated further using a Page planned comparisons test (Marascuilo & McSweeney, 1977; Page, 1963) and the mean data across conditions. This test used the means of the ranks of log reinforcer effect at each lag weighted by quadratic orthogonal polynomials. A significant quadratic effect was found \((k = 7\) conditions, \(N = 8\) reinforcers; \(z = -6.31, p < .05)\), showing that the effect of a reinforcer increased as the arranged reinforcer ratio became more extreme. Figure 4.3 shows these data in two ways: The upper panel in Figure 4.3 plots these mean data as a function of both the arranged log reinforcer ratio and reinforcer lag; and the lower panel plots log reinforcer effect at Lag 0 and the mean log reinforcer effect from Lags 1 through 7 as a function of the arranged log reinforcer ratio. These graphs show clearly the increases in log reinforcer effect as the log reinforcer ratios became more extreme. Moreover, the top panel shows that reinforcers beyond Lag 0 did not have any differential effects on current behaviour.

As described above, the constant \((\log k)\) in Equation 4.1 measures the residual current preference and inherent bias once the effects of each of the eight previous reinforcers have been removed. Thus, it might be best viewed as a biased measure of the more molar effect of the reinforcer ratio in the current condition. A one-way
ANOVA using the individual data confirmed that log $k$ did in fact change as the reinforcer ratio changed ($F_{6,28} = 26.87, p < .05$).

The use of an eight-reinforcer window in the above analyses shows how previous reinforcers affect current preference. However, given the large effects of reinforcers at Lag 0, and the smaller effects of reinforcers beyond Lag 0, it remains possible that a smaller window might suffice. Therefore, these analyses were repeated with the window size varied from one to eight reinforcers in length. Values of log reinforcer effect did not change in any systematic way as the window size was varied. Figure 4.4 shows the values of log $k$ obtained from these analyses plotted as a function of the window size for each subject in each condition. Nonparametric tests for trend (Ferguson, 1966) were used to confirm that in all conditions except Condition 1 (1:1) significant trends were evident with log $k$ becoming less extreme as the window size was increased. The $z$ scores obtained for each condition are shown in Figure 4.3. In addition to these trends, it is clear that the decreases in log $k$ were greater in conditions in which the reinforcer ratio was more extreme. These results support the earlier analysis suggesting that previous reinforcers did have an effect on current preference, and that this effect was greater when the reinforcer ratio was more extreme. Moreover, this analysis suggests that reinforcer control may have been relatively more local in Conditions where the reinforcer ratio was more extreme.
Figure 4.3 The upper panel shows log reinforcer effect plotted as a function of reinforcer lag and the log arranged reinforcer ratio, averaged over the five subjects. The lower panel shows log reinforcer effect at Lag 0, and the mean value across Lags 1 through 7, both as a function of the log arranged reinforcer ratio.
Figure 4.4  Log $k$ in each condition for each subject plotted as a function of the size of the moving window used in the analyses. Also shown are the $z$ scores obtained from nonparametric tests for trend in each condition.
4.3.3 Reinforcer-by-reinforcer analyses

A local analysis broke the data into log response ratios emitted in inter-reinforcer intervals following every sequence of reinforcers obtained in a condition. A sliding window nine reinforcers in length was used. Thus, before the first reinforcer in a sequence, one log response ratio could be calculated. After the first reinforcer, and before the second, two log response ratios were available (one following a red reinforcer, and one following a green reinforcer). After two reinforcers in a sequence, four log response ratios were available, one for each possible two-reinforcer sequence, and so on.

Figure 4.5 shows the log response ratios emitted following sequences of successive red or green reinforcers, and the effects of a single disconfirmation at each sequential position in each condition. Data were omitted from Figure 4.5 if fewer than 30 responses were recorded at either alternative. Substantial local effects of individual reinforcers were evident in the present data. Specifically, successive reinforcers obtained from the same alternative generally moved preference towards the alternative from which they were obtained, irrespective of the reinforcer ratio arranged in that condition. Disconfirmations, in contrast, had comparatively very large effects on preference.

The tree structures shown in Figure 4.5 were clearly asymmetrical, unlike those seen in Chapter 3 and elsewhere (Davison & Baum, 2000; Landon & Davison, 2001). Successive same-alternative reinforcers obtained at the alternative providing the lower rate of reinforcement had larger effects on the log response ratio in the next inter-reinforcer interval than those obtained at the alternative providing the higher rate of reinforcement. In each condition, there was an apparent limit on how far preference moved following sequences of same alternative reinforcers obtained at the
alternative providing the higher rate of reinforcement, and these limits were ordered in the same way as the reinforcer ratios. Moreover, the tree structures as a whole were biased toward the alternative providing the higher rate of reinforcement.

4.3.4 Behaviour in inter-reinforcer intervals

An even more local analysis was used to examine behaviour during inter-reinforcer intervals in each condition. To do this, the data were collated across subjects in 2-s time bins following all possible two-reinforcer sequences. Separate log response ratios were calculated for each 2-s bin following each of the four sequences of reinforcers and Figure 4.6 shows the log red/green response ratio in each 2-s bin for each sequence plotted as a function of time since reinforcement.

Figure 4.6 shows that preference in the first 2-s bin following a reinforcer delivery was always exclusive to the alternative at which a reinforcer was just obtained, and this was also the true in 22 of 32 cases in the second 2-s bin after a reinforcer delivery. A number of consistencies are evident across conditions. First, a single reinforcer in each condition resulted in a large transient shift in preference towards the alternative at which it was obtained. For example, in Condition 1 (equal reinforcer ratios), the effects of a red or green-alternative reinforcer were superimposable: In the first six bins after reinforcement, a strong preference was evident for the just-reinforced alternative, and thereafter the log response ratios remained at a stable level close to zero. In other conditions similar transient movements in preference were also evident. Across conditions, however, preference stabilised at levels that changed as a function of the log reinforcer ratio arranged in that condition, and thus might be considered analogous to log $k$ above.
Some representation of the quadratic effect of the reinforcer ratio on log reinforcer effect seen in Figure 4.3 might also be expected in Figure 4.6. Indeed, a similar effect was evident in the duration of the transient movement in preference. If Condition 1 (1:1) is considered, preference had returned to stable levels by about the twelfth 2-s bin following a reinforcer delivery. This includes a small reversal of preference in Bins 7 to 11. In Condition 4 (9:1), preference had not returned to its stable level until about the sixteenth 2-s bin following a reinforcer delivery on the higher reinforcer-rate alternative, and in Condition 2 (27:1) this was not the case until about the twenty-first 2-s bin. Thus, Figure 4.5 shows that, across conditions, the duration of the transient movement in preference increased following a reinforcer at the higher reinforcer-rate alternative as the reinforcer ratio increased.

4.3.5 Response rates

Figure 4.7 shows the mean number of responses emitted in each successive 2-s bin following each of the four sequences of reinforcers as a function of time since reinforcement. Data were omitted when a particular time bin was reached on fewer than five occasions. The filled circles show behaviour when the most recent reinforcer was obtained at the red alternative, and the open circles show behaviour when the most recent reinforcer was obtained at the green alternative. In all conditions, following all the sequences shown, the response rate emitted in the first 2-s bin was low. Response rates were, in general, similar across conditions, and it is clear that they were unaffected by whether the most recent reinforcer was from the same or opposite alternative to the preceding reinforcer. However, in conditions where the reinforcer ratio was unequal, there were differences in the response rates emitted in the first four to six bins after a reinforcer delivery. In all cases, the
response rate emitted following a reinforcer obtained from the leaner alternative were substantially lower than those emitted following a reinforcer at the richer alternative. These response rates were equal by the sixth or seventh 2-s bin after a reinforcer delivery.
Figure 4. 5 Log response ratios emitted in inter-reinforcer intervals following successive same-alternative reinforcers (solid lines). The broken lines join "disconfirmations", where a reinforcer was obtained from the other alternative.
following sequences of successive same-alternative reinforcers. A sliding window
nine reinforcers in length was used throughout, and data were omitted if fewer than 30
responses were recorded at either alternative.

Figure 4.6 The log response ratio emitted in successive 2-s time bins in
Experiment 2a following the four possible two-reinforcer sequences. Also plotted are
reference lines indicating zero on each y-axis.
Figure 4.7 The mean number of responses emitted in successive 2-s time bins following the four possible two-reinforcer sequences. Data were omitted when a particular time bin was reached fewer than five times.
4.4 Discussion

The present results were described well by the GML (Baum, 1974), and yielded parameters consistent with previous concurrent VI VI manipulations (Davison & McCarthy, 1988; Taylor & Davison, 1983). The present results also showed that the effects of individual reinforcers evident in frequently changing conditions (Davison & Baum, 2000) were also evident in a steady-state procedure. Thus, the local effects of reinforcers shown by Davison and Baum could not be attributed solely to the rapidly changing contingencies they arranged.

The analyses of the effects of preceding reinforcers on behaviour (Figures 4.2 and 4.3) showed that each of the previous eight reinforcers had a small but generally positive effect on current preference. The one difference evident in the effects of these reinforcers was that the most recently obtained reinforcer had a substantially larger effect on preference than the preceding ones. It was also the case that reinforcers obtained in conditions where the reinforcer ratio was more extreme had larger effects (see Figure 4.3). This was further supported when the window size was varied (Figure 4.4). Log $k$ decreased as window size was increased as would be expected if each reinforcer were indeed having a significant effect on current preference. Moreover, log $k$ decreased more quickly when the reinforcer ratio was more extreme. This might have been expected given that each reinforcer had a greater effect on current preference in these conditions.

The latter finding suggests that control was relatively more local in conditions with more extreme reinforcer ratios. These findings are somewhat similar to the effect of context reported in Chapter 3 (Experiment 1a, see also Landon and Davison, 2001). However, the effect reported by Landon and Davison was one of range of variation, whereas in the present experiment the effect seems to be due to extremity of
the reinforcer ratio. This context effect was also evident when preference was analysed in successive 2-s bins during inter-reinforcer intervals (Figure 4.6). In this case, the duration of the shifts in preference, rather than their magnitudes, on the higher reinforcer-rate alternative increased with increasing reinforcer ratio.

Unfortunately, none of the conditions in Experiment 1c (Chapter 3), in which only one component reinforcer ratio was arranged, arranged a reinforcer ratio comparable to the 27:1 or 1:27 ratios used in the present experiment.

The analyses shown in Figures 4.2, 4.3, and 4.4 are particularly important because, in addition to showing clear short-term effects of individual reinforcers, they also provided evidence for substantially longer-term effects of aggregations of reinforcers. The constant (log \(k\)), measuring more molar effects of reinforcement, changed across conditions as a function of the reinforcer ratio in effect. A similar effect was also evident in Figure 4.6 where the levels at which preference stabilised after a reinforcer delivery changed so that they were ordered in the same way as the reinforcer ratios arranged in each condition. Thus, there was converging evidence suggesting both long- and short-term effects of reinforcers on behaviour, and that control was not purely local as suggested by Davison and Baum (2000).

The log response ratios at which preference stabilised during inter-reinforcer intervals (Figure 4.6) were less extreme than the log \(k\) values obtained from the analysis of control by previously obtained reinforcers (Figure 4.3). This occurred because short inter-reinforcer intervals were much more common than long intervals. Thus, most of the behaviour from which log \(k\) values were derived came from the left-hand end of the functions shown in Figure 4.6, where preference was relatively extreme. This makes the orderly relationship between the stable preferences shown in Figure 4.6 and the reinforcer ratio in each condition more noteworthy, because it
represents control by the reinforcer ratio in each condition even when no reinforcers had been obtained for much longer than the average scheduled inter-reinforcer interval.

The trees (Figure 4.5) were generally consistent with the effects of the reinforcer ratios already discussed (e.g., Figure 4.6). In each condition, the entire tree moved towards the alternative providing the higher rate of reinforcement, with apparent upper limits to preference, ordered in the same way as the reinforcer ratios in each respective condition. However, Figures 4.5 and 4.6 show apparent discrepancies in the effects of disconfirmations and successive same-alternative reinforcers. Figure 4.5 shows large effects of disconfirmations, and comparatively small effects of successive same-alternative reinforcers at a reinforcer-by-reinforcer level. In contrast, Figure 4.6, shows that in inter-reinforcer intervals there were large effects of reinforcers obtained from the richer alternative, and small effects of reinforcers obtained from the leaner alternative irrespective of whether the reinforcer was obtained from the same, or the opposite alternative to the preceding reinforcer. Given this, and that Davison and Baum (2000) used the term disconfirmation to describe a reinforcer that broke a sequence of same-alternative reinforcers in conditions in which symmetrical distributions of reinforcers were arranged, it seems best, in the present context, to consider disconfirmations as reinforcers obtained at the leaner alternative in conditions in which non-zero log reinforcer ratios have been arranged.

Where Figure 4.5 shows sequences of successive reinforcers obtained at the richer alternative, these log response ratios would again have consisted mainly of behaviour from the left-hand end of the functions shown in Figure 4.6, where preferences were relatively extreme and response rates were higher than those emitted following a reinforcer at the leaner alternative (Figure 4.7). Because the durations of
the transient movements in preference changed across conditions with the reinforcer ratio, the average log response ratios emitted in inter-reinforcer intervals would have become more extreme. Thus, the upper limits of the trees changed across conditions. Where Figure 4 shows disconfirmations, the transient changes in preference following these reinforcers were much shorter, and, as Figure 4.7 shows, the response rate was much lower during the transient change in preference. Thus, disconfirmations resulted in preferences very similar to the stable levels shown in Figure 4.6.

Davison and Baum (2002), using the rapidly changing procedure outlined earlier (Davison & Baum, 2000), reported that during periods of extinction following each component preference moved towards indifference, irrespective of the reinforcer ratio in that component. This finding, at first, seems inconsistent with the present results, which showed that the reinforcer ratio controlled behaviour even after uncommonly long periods without reinforcement. However, Davison and Baum's procedure arranged seven reinforcer ratios (1:27 through 27:1) that were symmetrical around 1:1. Since their sessional reinforcer ratio was 1:1, it is not possible to distinguish between a shift towards indifference and a shift towards the sessional reinforcer ratio. That is, the present interpretation, emphasising control by the reinforcer ratio in each condition, is also consistent with Davison and Baum's (2002) result.

The present results show that the local effects of reinforcers evident in Experiment 1, and those reported by Davison and Baum (2000, 2002) were not solely a result of the rapidly changing contingencies. Even in a steady-state concurrent-schedule procedure significant local effects of reinforcers were evident. The present results also paralleled those from Conditions 8, and 24 to 28, of Experiment 1 where contingencies were arranged that were similar to steady-state concurrent schedules.
This research, as a whole, suggests a need to re-examine how the variables controlling concurrent performance are viewed. The GML (Baum, 1974) has been used to describe a wide variety of concurrent schedule research (Davison & McCarthy, 1988). Given the regularities evident at this more molar level of analysis, it has been assumed, often implicitly, that behaviour is controlled by relatively large aggregations of reinforcers. Indeed, the present results were also described well at this more molar level of analysis. The more local analyses, however, also showed evidence of longer-term control by larger aggregations of reinforcers. Clearly, a full understanding of choice behaviour requires analysis at multiple levels, and some integration of short- and longer-term effects of reinforcers.
4.5  Experiment 2b

Much of the reported concurrent-schedule research has focused on the effects of either the relative frequency of reinforcement or schedule type on behaviour (for a review see Davison & McCarthy, 1988). Reinforcers, however, can be varied along a number of other dimensions such as magnitude, delay, and quality. In fact, both the strict and the generalized matching laws have been extended to include such variations (Baum & Rachlin, 1969; Killeen, 1972). The latter assumes that the effects of each such independent variable are independent, and that each variable has its own sensitivity parameter. The present experiment involves an empirical investigation of the effects of variations in reinforcer magnitude on behaviour at a number of levels of analysis. To date, relatively few studies have investigated the effects of reinforcer magnitude, and the literature remains ambiguous on its effects relative to reinforcer frequency manipulations.

Catania (1963a) reported an early investigation of the effects of reinforcer magnitude using concurrent schedules. Pigeons' responses were reinforced according to independent concurrent VI 2-min VI 2-min schedules with reinforcer durations at the two alternatives varied in a systematic way across four conditions. He also arranged a series of conditions with a single VI schedule in which reinforcer magnitude was varied from 4 to 6 s. When he plotted the rate of responding to the single VI schedule as a function of reinforcer magnitude he found no effect. However, when the equivalent data from one alternative during the concurrent schedule conditions were examined response rate was a linear function of reinforcer magnitude. Catania suggested that this relationship was very similar to that reported for reinforcement rate (Herrnstein, 1961).
Schneider (1973) investigated the effects of reinforcer magnitude using a two-key concurrent-schedule procedure. The procedure was slightly unusual in that reinforcers were delivered at the two alternatives in an irregular predetermined order that was changed every three sessions. Schneider varied reinforcer magnitude by delivering different numbers of food pellets to the subjects, and he also varied the reinforcer ratio across conditions. When he plotted the ratio of responses to the two alternatives as a function of the ratio of the rates of reinforcement, Schneider found the former undermatched the latter. He repeated the analysis, this time using the ratio of reinforcer magnitudes as the independent variable and found the degree of undermatching was even greater. He used logarithmic transformations of the data and linear regressions to calculate values of what could be termed sensitivity to reinforcer frequency (0.60) and sensitivity to reinforcer magnitude (0.34). Thus, Schneider concluded that differences in reinforcer frequencies exerted greater control over behaviour than differences in reinforcer magnitudes.

Todorov (1973), using an even more unusual procedure, found very similar results. His switching-key concurrent-schedule procedure consisted of three different VI schedules, each associated with a different key colour. A given key colour was associated with one schedule of reinforcement throughout the experiment, but the duration of reinforcement associated with each colour was varied across conditions from 2 to 5 s. Each of the three combinations of schedules was presented once in a session for a total of 20 reinforcer deliveries each. Todorov reported mean values for sensitivity to reinforcer frequency of 0.90, and sensitivity to reinforcer magnitude of 0.27.

Keller and Gollub (1977) used a more standard two-key concurrent-schedule procedure. In their Experiment 1, they varied both reinforcer frequencies (overall
constant at 60 per hour) and reinforcer durations (sum always 6 s). Keller and Gollub calculated, but did not publish, values of sensitivity to reinforcer rate and reinforcer magnitude. They did, however, argue that their results were inconsistent with those of Schneider (1973) and Todorov (1973) in that there was not “a consistently greater degree of behavioural control by reinforcement rate than by reinforcement duration” (p. 149). However, a reanalysis reported by Davison and McCarthy (1988) shows that, as acknowledged by Keller and Gollub, their results were not consistent across subjects. Nonetheless, in two out of three cases sensitivity to reinforcer frequency was higher than sensitivity to reinforcer magnitude, with the group values being 0.62 and 0.50 respectively.

In their Experiment 2, Keller and Gollub (1977) examined the possibility that prolonged exposure to a variety of magnitudes and frequencies of reinforcement might attenuate concurrent-schedule control (see also Todorov et al., 1983). Each subject was exposed to a different arrangement where the reinforcer-frequency ratio, the reinforcer-magnitude ratio, or both were varied. Keller and Gollub showed that, in these conditions, response rates more closely approximated the relative total reinforcement access time. This result was interpreted as suggesting the continued exposure to variations as in their Experiment 1 suppressed sensitivity values. Davison and McCarthy (1988) reanalysed these data, and reported that sensitivity to reinforcer frequency and magnitude values were both 1.06, but both values had relatively large standard deviations (0.11 and 0.20, respectively). Moreover, as Davison and McCarthy point out, Keller and Gollub changed from arithmetic schedules in Experiment 1, to exponential schedules (which generally result in increased sensitivity values, see Taylor & Davison, 1983) in Experiment 2, which in retrospect was a major confound. Thus, it remains that the experimental evidence suggests that
control by variations in reinforcer frequencies is greater than control by variations in reinforcer magnitudes (Keller & Gollub, 1977 Experiment 1, Schneider, 1973; Todorov, 1973).

Another relatively unusual procedure was used by Todorov, Hanna and Bittencourt de Sa (1984) to investigate the effects of reinforcer magnitude on concurrent-schedule performance. They exposed pigeons to 29 sessions, each eight hours in duration, in which the reinforcement parameters changed every session. In the first nine sessions, reinforcer magnitudes were always equal and reinforcer frequencies were varied across the two alternatives. In the second nine sessions, both reinforcer frequencies and reinforcer magnitudes were varied. In the final ten sessions, reinforcer frequencies were held constant and equal while reinforcer magnitudes were varied. Todorov et al. showed that hour-by-hour sensitivity to reinforcer frequency values (range 0.81 to 1.13) were higher than sensitivity to reinforcer magnitude values (0.23 to 0.62), irrespective of whether both variables were manipulated or each was manipulated individually. Moreover, these values, obtained using a novel procedure, were consistent with previous research investigating reinforcer magnitude (Keller & Gollub, 1977 Experiment 1, Schneider, 1973; Todorov, 1973) and research manipulating only relative rates of reinforcement (Taylor & Davison, 1983).

McLean and Blampied (2001) investigated whether the assumption made in the GML that sensitivity to reinforcer frequency was independent of both absolute and relative reinforcer magnitudes held. A standard two-key concurrent-schedule procedure was used and over several series of conditions relative and absolute magnitudes of reinforcement were varied. Within each series the relative frequencies of reinforcement over the two alternatives were varied enabling values of sensitivity
to reinforcer frequency to be calculated. Their results showed that sensitivity to reinforcer frequency was the same irrespective of the absolute magnitude of the reinforcers. Moreover, it was also unaffected by the reinforcer magnitude being unequal for the two alternatives. However, behaviour was biased towards the alternative at which the larger reinforcers were obtained. Thus, the assumptions made in the GML that sensitivity to reinforcer frequency would be independent of absolute and relative reinforcer magnitudes were supported.

In contrast, Davison and Hogsden (1984) have reported a result that is problematic for the generalized matching approach. In Part 5 of their experiment, Davison and Hogsden arranged constant VI 120-s schedules on both keys of a two-key concurrent-schedule procedure. Over five conditions they held the right-key reinforcer magnitude constant at 3 s, and varied the left-key reinforcer magnitude from 1 to 10 s. None of the previous studies had undertaken an extensive manipulation of reinforcer magnitudes while retaining a constant reinforcer frequency. Davison and Hogsden plotted the log response ratios as a function of the log reinforcer-magnitude ratios. Rather than being linear as the GML would suggest, the data were clearly non-linear. Log response ratios showed a positively accelerating increase with increasing log reinforcer-magnitude ratios.

Davison and Hogsden (1984) pointed out that the GML for reinforcer magnitude had been generally accepted on the basis of relatively few data. To interpret their result, they first considered their data in terms of the amount of food consumed rather than the time for which access to food was provided (Schneider’s (1973) study is the only one reported which arranged discrete amounts of food as reinforcers). Epstein (1981) has shown that the amount of food consumed by pigeons is a negatively accelerating function of reinforcer duration, but this implies a concave
downward function should have been evident in Davison and Hogsden’s data. Davison and McCarthy (1988) considered the idea that the subjects took a constant time to move from the key to the food magazine. However, adjusting the reinforcer magnitudes in this manner did little to make the data more linear. Davison and Hogsden’s result suggests that sensitivity to reinforcer magnitude, rather than being a constant, depended on the absolute magnitudes of the reinforcers.

Logue and Chavaro (1987) noted a further problem. In their Experiment 2, pigeons responded on concurrent VI 8-s VI 8-s schedules with a constant 3:1 reinforcer magnitude ratio (the absolute magnitudes were varied) and a 9-s delay to reinforcer delivery at both alternatives. Logue and Chavaro showed that preferences increased as the absolute magnitudes of reinforcers were decreased. Davison (1988) reported an experiment where he arranged unequal reinforcer magnitudes over a series of conditions. Across these conditions he always arranged equal schedules of reinforcement, but varied their absolute values. The results showed that as the overall rate of reinforcement was increased, preference became less extreme, and values of sensitivity to reinforcer magnitude decreased. These values were, however, already much lower than equivalent values of sensitivity to reinforcer frequency.

To summarise, the research on the effects of reinforcer magnitude on behaviour is notable for its paucity. To begin with, the term reinforcer magnitude is ambiguous. Most of the studies above, with the exception of Schneider (1973), varied what would be more accurately termed reinforcer duration, and indeed some (Davison, 1988; Davison & Hogsden, 1984; McLean & Blampied, 2001) have used this more accurate label. The term magnitude has been retained here in a more generic sense, particularly because the manipulations made in the present experiment are perhaps not most accurately described as reinforcer duration. The research
outlined above has shown, with one questionable exception (Keller & Gollub, 1977),
that changes in the relative frequency of reinforcers exert greater control over
behaviour than changes in the relative magnitudes of reinforcers. However, some
research (Davison, 1988; Davison & Hogsden, 1984; Logue & Chavarro, 1987) has
seriously questioned the applicability of the GML as a description of behaviour given
these manipulations.

Davison (1988) suggested the need for more data to guide in the possible
development of quantitative models to account for choice behaviour given variations
in reinforcer frequency and reinforcer magnitude. Unfortunately, with one exception
(McLean & Blampied, 2001), this suggestion has been ignored. No published paper,
with the exception of Davison and Hogsden (1984), has arranged sufficient
manipulations of reinforcer magnitude with a constant relative frequency of
reinforcement in a standard concurrent-schedule procedure, so that a generalized
matching type analysis could be done (Davison & Hogsden varied both the relative
and absolute magnitudes of reinforcement). The present experiment provides a
systematic empirical investigation of the effects of reinforcer magnitude in a standard,
steady-state, concurrent-schedule procedure with the relative frequency of
reinforcement held constant. Reinforcer magnitude was varied by changing the
number of short (1.2 s) hopper presentations across conditions. In all conditions, the
sum of the number of hopper presentations was constant at eight.

Experiment 2a showed clearly that the local effects of individual reinforcers
evident in frequently changing procedures (Chapter 3, Davison & Baum, 2000; 2002;
Landon & Davison, 2001) were also present in a standard steady-state procedure.
However, as was shown in Chapter 3, it was also clear that the variables controlling
behaviour were neither purely local, nor purely molar in nature. Reinforcers had
effects that seemed to be cumulative at a number of levels. Whether this would be the case when reinforcer magnitude was varied was not clear as varying reinforcer frequency and reinforcer magnitude are inherently different: An unequal reinforcer frequency increases or decreases the likelihood that the next reinforcer will be available at the same alternative as the prior one; an unequal reinforcer magnitude (with equal frequency of reinforcement) leaves this unchanged, but the reinforcers available at one alternative are always larger. It is possible to speculate on the level at which control, give such a variation, would be manifested. For example, given that reinforcer magnitude was invariant across a condition, control might be expected to be more molar in nature than when reinforcer frequency was varied. Such speculation, in the absence of data, is not warranted. Thus, in the present experiment, five variations of reinforcer magnitude were arranged while the reinforcer-frequency ratio across the two alternatives was held constant. The data collected were analysed at a number of levels of analysis.

4.6 Method

Subjects and Apparatus.

The subjects and apparatus were the same as those used in Experiment 2a.

Procedure.

The same standard switching-key (Findley, 1958) concurrent-schedule procedure as used in Experiment 2a was used here. The only change concerned the delivery of a reinforcer. Reinforcers consisted of a specified number of successive 1.2-s hopper presentations. These presentations were separated by 0.5-s blackouts. Thus, reinforcer magnitude was varied by changing the number of successive hopper presentations at each alternative.
Sequence of experimental conditions, relative reinforcer probability (shown as probability of reinforcement on the red alternative), and the reinforcer magnitude ratio (in number of hopper presentations) for each of the five conditions in Experiment 2b. The overall probability of reinforcement per second was constant at .033 throughout.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Relative reinforcer probability $p(R)$</th>
<th>Reinforcer magnitude ratio $(R:G)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>.5000</td>
<td>2:6</td>
</tr>
<tr>
<td>10</td>
<td>.5000</td>
<td>6:2</td>
</tr>
<tr>
<td>11</td>
<td>.5000</td>
<td>1:7</td>
</tr>
<tr>
<td>12</td>
<td>.5000</td>
<td>4:4</td>
</tr>
<tr>
<td>13</td>
<td>.5000</td>
<td>7:1</td>
</tr>
</tbody>
</table>

The sequence of experimental conditions is shown in Table 4.2. Across conditions, the overall rate of reinforcement was constant, as was red/green reinforcer ratio, which was always 1:1. The total number of hopper presentations to both alternatives was always eight (9.6 s access to wheat), and the relative magnitudes varied over five conditions from 7:1 to 1:7 as shown in Table 4.2. As previously, no stability criterion was in effect. However, 65 sessions were conducted for each condition to ensure sufficient data were collected to allow analysis of particular sequences of reinforcers. The data from the last 50 sessions of each condition were used in the analyses. Sessions were conducted daily, and ended in blackout after 80 reinforcers had been obtained, or after 42 min had elapsed, whichever occurred first.
4.7 Results

4.7.1 Generalized matching

Figure 4.8 shows the logs of the red over green response- and time-allocation ratios plotted as a function of the logs of the red over green reinforcer magnitude ratios. The magnitudes used were the total access to wheat, thus the 0.5-s periods between hopper presentations were discarded. Equation 4.2 was then fitted to the data by means of least squares linear regression:

$$\log \left( \frac{B_1}{B_2} \right) = a \log \left( \frac{M_1}{M_2} \right) + \log c,$$

(4.2)

where $M$ is the magnitude of the reinforcers obtained at Alternatives 1 and 2 respectively. The equations for each of the fitted lines are shown above (time allocation) and below (response allocation) the lines. The percentage of variance accounted for was always high, indicating the lines fitted the data well. Biases were small, except for the behaviour of Bird 136, and generally towards the green alternative. The slopes of the fitted lines which indicate sensitivity to reinforcer magnitude, ranged from 0.70 to 0.87 (mean = 0.76) for response allocation, and from 1.06 to 1.32 (mean = 1.15) for time allocation. Thus, these values were higher than those estimated in previous research (Keller & Gollub, 1977; Schneider, 1973; Todorov, 1973; Todorov, et al., 1984). Nonetheless, in nine of ten comparisons (binomial, $p < .05$; Bird 136’s time allocation was the exception) these values were lower than the sensitivity to reinforcer frequency values obtained from these same subjects (see Experiment 1a). Moreover, in all cases response measures of sensitivity to reinforcer magnitude were lower than corresponding time measures, consistent with the general findings in concurrent-schedule research (Elliffe & Alsop, 1996; Taylor & Davison, 1983).
Figure 4.8. Log response- and time-allocation ratios plotted as a function of the log reinforcer magnitude ratios for each subject in each condition of Experiment 2b. The straight lines were fitted by means of least squares linear regression, and the equations are shown on the graphs.
4.7.2 Current preference and previous reinforcers

The analysis reported in Experiment 2a (Section 4.3.2) was repeated here. To review, a moving window of the eight most recently obtained reinforcers was used. Thus, 256 distinct sequences of red and green reinforcers were possible. Beginning with the eighth reinforcer in a session, red and green response numbers after each successive reinforcer were aggregated according to which of those 256 sequences they followed, and a log red/green response ratio calculated as a measure of current preference. Unlike in Experiment 2a, the present experiment always arranged a reinforcer-frequency ratio of 1:1, and as a result there were no occasions where a particular sequence of reinforcers did not occur. However, there remained an occasional instance where preference following a particular sequence was exclusive, and no response ratio could be calculated.

The best-fitting least-squares estimates of log reinforcer effect ($b_j$) and log $k$ were again obtained by fitting Equation 4.1 to the log response ratios following each eight-reinforcer sequence using Quattro Pro® v. 8's Optimizer function. This analysis was carried out separately for each condition and for each subject. Figure 4.9 shows log reinforcer effect of each of the preceding reinforcers plotted as a function of reinforcer lag (Lag 0 is the most recent reinforcer) for each subject in each condition. The constant (log $k$) is also shown for each subject in each condition.

Figure 4.9 shows three clear effects: First, the most recently obtained reinforcer again had by far the largest effect on current preference; second, reinforcers beyond Lag 0 had similar small effects on current preference; third, the constant log $k$ became more extreme as the reinforcer magnitude ratios were made more extreme.
Figure 4.9. Log reinforcer effect for each of the previous eight reinforcers plotted as a function of reinforcer lag (0 being the most recently obtained reinforcer) for each subject in Experiment 2b. Also shown are values of log $k$ (see Equation 4.1) for each subject.
For consistency, the same statistical analyses that were used for Experiment 1a were repeated. First, a two-way repeated-measures ANOVA was used to examine any possible effects of the reinforcer magnitude ratio and of the sequential position of the reinforcer on log reinforcer effect. This ANOVA showed that neither the reinforcer magnitude ratio ($F_{3,112} = 1.80, p > .05$), nor the sequential position of the reinforcer ($F_{6,112} = 1.30, p > .05$) had a significant effect on log reinforcer effect. A one-way ANOVA using the individual data was used to confirm the effect shown in Figure 4.9 that log $k$ did change as the reinforcer ratio changed ($F_{4,20} = 100.63, p < .05$).

Given that the reinforcer magnitudes arranged in Experiment 2b were, apart from Condition 12, unequal, it was of interest to consider log reinforcer effect following red and green reinforcers separately. Thus, the following equation was fitted to the data as previously:

$$\log \left( \frac{B_R}{B_G} \right) = \log k + \sum_{j=0}^{7} \begin{cases} R_j = R : & + b_R \\ R_j = G : & - b_G \end{cases},$$

(4.3)

The parameters are identical to those described for Equation 4.1, except that separate values of log reinforcer effect were estimated for reinforcers obtained at the red ($b_R$) and green ($b_G$) alternatives.
Figure 4.10. Log reinforcer effect for each of the previous eight reinforcers plotted separately for the two alternatives (\(b_r\) and \(b_g\), see Equation 4.3) as a function of reinforcer lag (0 being the most recently obtained reinforcer) for each subject in Experiment 2b. Also shown are values of log \(k\) for each subject.

Figure 4.10 shows the results of this analysis for each subject in Conditions 12, 9, and 11. The data from Condition 12 (4:4) show that a reinforcer at Lag 0 had a large effect on preference, while reinforcers beyond Lag 0 had small, generally
positive, effects on current preference. In Conditions 9 (2:6) and 11 (1:7) clear and regular changes occurred in the values of log reinforcer effect. Within conditions, reinforcers obtained at the alternative providing the larger reinforcers had both larger and more positive effects on current preference. Also, in the right panels, as the reinforcer magnitude (and the ratio) was increased there was an increase in the values of log reinforcer effect at all lags. In the left panels, as the reinforcer magnitude decreased (as the ratio was changed) there was a corresponding decrease in the values of log reinforcer effect. Reinforcers at Lag 0 continued to have a positive, but progressively smaller, effect on current preference. Reinforcers beyond Lag 0 in Condition 11 had negative effects on current preference, and in Condition 9 this was the case in 33 of 35 estimates. Moreover, with the exception of Condition 12 (4:4), log reinforcer effect beyond Lag 0 was more positive for a larger reinforcer than it was negative for a smaller reinforcer. This effect was significant across all conditions on sign tests (p < .05).

4.7.3 Reinforcer-by-reinforcer analyses

The same local analysis used in Experiment 2a (Figure 4.5) was also repeated here. To review, the data were broken into log response ratios emitted in inter-reinforcer intervals following every sequence of reinforcers obtained in a condition using a sliding window nine reinforcers in length. Thus, before the first reinforcer in a sequence, one log response ratio could be calculated. After the first reinforcer, and before the second, two log response ratios were available (one following a red reinforcer, and one following a green reinforcer). After two reinforcers in a sequence, four log response ratios were available, one for each possible two-reinforcer sequence, and so on.
Figure 4.11. Log response ratios emitted in inter-reinforcer intervals following successive same-alternative reinforcers (solid lines). The broken lines join “disconfirmations,” where a reinforcer was obtained from the other alternative following sequences of successive same-alternative reinforcers. A sliding window nine reinforcers in length was used throughout.
Figure 4.11 shows the log response ratio emitted following sequences of red or green reinforcers obtained in succession, and the effects of a single disconfirmation at each sequential position in each condition. The same substantial local effects of individual reinforcers evident in previous experiments reported in this thesis were again evident in the present data. In general, successive reinforcers obtained from the same alternative moved preference towards the alternative from which they were obtained, irrespective of the reinforcer magnitude ratio arranged in that condition. Disconfirmations, in contrast, had comparatively very large effects on preference.

In all five conditions shown in Figure 4.11, the tree structures were reasonably symmetrical, unlike those shown in Figure 4.5 when the reinforcer-frequency ratios were manipulated. Across conditions, no systematic differences in the log response ratios emitted after identical sequences of left and right reinforcers were evident. Thus, the tree structures were very similar across conditions. The effect of the differences in reinforcer magnitude ratios arranged across conditions was seen in the tree structures as a whole shifting towards the alternative that arranged the larger reinforcers. The sizes of these movements were ordered in the same way as the reinforcer magnitude ratios themselves.

4.7.4 Behaviour in inter-reinforcer intervals

Figure 4.12 shows the log red/green response ratios emitted in each successive 2-s bin following a reinforcer delivery for the four possible two-reinforcer sequences. As was the case in Experiment 2a, preference in the first few 2-s bins following a reinforcer delivery was often exclusive. First, consider Condition 12 (4:4 reinforcer magnitude ratio). Performance here accurately replicated that from the more standard procedure reported earlier (Condition 1) in which both the reinforcer magnitudes and
frequency of reinforcement were equal for the two alternatives (see Figure 4.6). In this condition (as was the case for Condition 1), the effects of red- and green-alternative reinforcers mirrored one another: In the first six bins after a reinforcer delivery, a preference was evident for the just-reinforced alternative. A small preference reversal occurred in bins eight to twelve, and for subsequent bins the log response ratios were relatively stable at a level close to zero.

As the reinforcer magnitudes were made unequal across conditions, several regular changes were evident in the data. First, the stable levels of behaviour in the inter-reinforcer intervals changed so that they favoured the alternative providing the larger reinforcers. These changes were ordered in the same way as the reinforcer magnitude ratios. The durations of the transient movements in preference towards the just-reinforced alternative increased when that alternative was providing large reinforcers. In Condition 13 (7:1), preference following a red reinforcer favoured the red alternative for the first twelve 2-s bins. The same was true in Condition 10 (6:2), although the size of the preference was smaller. In the same conditions at the alternative providing the smaller reinforcers the transient movements in preference were much shorter (two and four 2-s bins respectively). It was again the case that preference did not stabilise until about the thirteenth 2-s bin following a reinforcer delivery. Following the short movement in preference towards the just-reinforced alternative was a movement towards the alternative providing the larger reinforcers. This movement went beyond the stable levels in each condition. Thus, across Conditions 9 to 13 the durations of the transient changes in preference following a reinforcer delivery remained constant. However, the size of these changes, and the stable levels of preference following their occurrence changed as a function of the reinforcer magnitude ratios arranged.
Figure 4.12. The log response ratio emitted in successive 2-s time bins in Experiment 2b following the four possible two-reinforcer sequences. Also plotted are reference lines indicating zero on each y-axis.

4.7.4 Response rates

Figure 4.13 shows the mean number of responses emitted in each successive 2-s bin following each of the four sequences of reinforcers considered above as a
function of time since reinforcement. The filled circles show behaviour when the most recent reinforcer was obtained at the red alternative, and the open circles show behaviour when the most recent reinforcer was obtained at the green alternative. In all conditions, following all the sequences shown, the response rate emitted in the first 2-s bin was very low. In Condition 9 it is evident that in Bins 2 to 8, response rates were higher following a green reinforcer than following a red reinforcer. This period corresponds with a period of extreme preference for the just-reinforced alternative (Figure 4.12). This is consistent with both Figure 4.8, where it was shown that the behaviour of all subjects contained a small bias towards the green alternative, and with previous research (Krägeloh, 2001), which has shown biases to be more prevalent soon after a reinforcer delivery. In other conditions it was the case that response rates were higher following a reinforcer obtained at the alternative providing the larger reinforcers for the first two to five bins following a reinforcer delivery. Thereafter, systematic differences were not evident in response rates following reinforcers obtained at either alternative.
Figure 4.13. The mean number of responses emitted in successive 2-s time bins in Experiment 2b following the four possible two-reinforcer sequences.

4.8 Discussion

The present results were described well by a version of the GML (Equation 4.2, Baum, 1974, Killeen, 1972). Log response ratios were found to be a linear function of log reinforcer magnitude ratios. At more local levels of analysis it was
again the case that regularities were evident in the effects of individual reinforcers on
behaviour. Given the relative paucity of research that has varied reinforcer
magnitudes in a standard concurrent-schedule procedure, it is useful to consider
briefly the present research in the context of the existing literature that has
manipulated reinforcer magnitude.

When considered in the context of the sensitivity to reinforcer frequency
values calculated for Experiment 2a, the present data were consistent with the general
finding of previous research (Keller & Gollub, 1977 Experiment 1, Schneider, 1973;
Todorov, 1973, Todorov et al., 1984), that varying reinforcer magnitudes exerted less
control over behaviour than varying reinforcer frequency. However, the sensitivity to
reinforcer magnitude values calculated here were higher than those reported
previously. Three obvious differences between the present procedure and those
reported previously might account for this: First, the present procedure arranged the
most systematic variation of reinforcer magnitude ratios with reinforcer-frequency
ratios held constant. This enabled estimates of sensitivity to reinforcer magnitude to
be calculated by least squares linear regression, meaning these estimates should have
been more accurate than those in previous research; second, the present procedure
consisted of a much greater number of sessions per condition, and, as Todorov et al.
(1983) showed, sensitivity to reinforcement may increase with the number of sessions
per condition; third, reinforcer magnitude was varied by arranging different numbers
of discrete hopper presentations. This differed from typical variations of reinforcer
magnitude (e.g., Davison & Hogsden, 1984; Todorov, 1973; Todorov et al., 1984),
and was more similar in nature to the discrete numbers of food pellets used by
Schneider. Replicating the present experiment using more standard manipulations of
reinforcer duration could investigate the latter possibility. However, these differences do not detract in any way from the present results.

The present results were inconsistent with the previous study that had arranged a systematic variation of reinforcer magnitude ratios (Davison & Hogsden, 1984). When Davison and Hogsden plotted log response ratios as a function of log reinforcer-duration ratios, the relationship was distinctly non-linear. Again, the reason for this difference is most likely a procedural one. Davison and Hogsden held the reinforcer duration constant at one alternative and varied the duration available at the other alternative. Thus, the overall reinforcer duration available across the two alternatives changed across conditions. In contrast, the overall reinforcer magnitude in the present experiment was held constant at a total of eight hopper presentations. As Davison and Hogsden pointed out, their result is a severe limitation on the GML's applicability. The result does, however, parallel the effect of overall reinforcer rate in concurrent schedules initially reported by Alsop and Elliffe (1988). In Davison and Hogsden's study log response ratios became more extreme as the overall reinforcer duration was increased. If, as would be expected, the linear relationship evident in the present data holds, this implies that sensitivity to reinforcer magnitude would increase as the overall reinforcer magnitude was increased. However, this must be tempered with the knowledge that schedule type affects the relationship between overall rate of reinforcement and sensitivity to reinforcement (Elliffe & Alsop, 1996).

Figures 4.9 and 4.10 show that both recently obtained reinforcers and reinforcers obtained in the more distant past had effects on current performance, with the most recently obtained reinforcer having the largest effect. Values of log \(k\) also changed as the reinforcer magnitude ratio was varied, indicating a longer-term effect of the reinforcer magnitude ratio. Unlike Experiment 2a, in which the relative
frequencies of reinforcers were varied, Figure 4.9 showed no effect of the relative reinforcer magnitudes on log reinforcer effect. However, when the log reinforcer effects for reinforcers at the two alternatives were considered separately (Figure 4.10), an effect was clear. Log reinforcer effect, for reinforcers obtained at the alternative providing the larger reinforcers, increased as the reinforcer magnitude ratio became more extreme (and the magnitude of the reinforcers at that alternative increased). Similarly, log reinforcer effect decreased for reinforcers obtained at the other alternative, and, with the exception of the most recently obtained reinforcer, became negative.

These negative values of log reinforcer effect were almost always smaller than the corresponding positive values for log reinforcer effect at the other alternative obtained in that condition; smaller reinforcers beyond Lag 0 had negative effects on current preference, but the positive effects of larger reinforcers were greater. Hence, Figure 4.9 shows reinforcers beyond Lag 0 having small positive effects on current preference. As mentioned above, log reinforcer effect (Figure 4.10) increased as reinforcer magnitude was increased. Given the symmetrical nature of the changes, as evidenced by the constancy in Figure 4.9, it seems likely that these changes were contextual in nature. That is, they were driven by the change in the relative magnitude of reinforcement rather than the change in the reinforcer magnitude at an alternative itself. This could be investigated more thoroughly arranging a constant reinforcer magnitude at one alternative, and varying reinforcer magnitude at the other alternative across a series of conditions as was done by Davison and Hogsden (1984).

The analyses of preference during inter-reinforcer intervals (Figure 4.12) also provided evidence of both short- and long-term effects of reinforcers. Across conditions, preference stabilised during inter-reinforcer intervals at levels that were
ordered in the same way as the reinforcer magnitude ratios. Again, this longer-term control was evident at periods well in excess of the typical inter-reinforcer interval. Shorter-term effects were seen in the transient movements in preference following a reinforcer delivery and were different at the two alternatives when unequal reinforcer magnitudes were arranged. At the alternative providing the larger reinforcers, these movements were large, lasting approximately 24 s before preference stabilised at a level that also favoured that alternative. At the alternative providing the smaller reinforcers, the transient movements in preference were similar in duration. However, they consisted of an initial shift in preference towards the just-reinforced alternative that lasted just 4 to 8 s. This was followed by a period in which preference moved towards the alternative providing the larger reinforcers, beyond the stable levels evident later in the inter-reinforcer intervals, before returning to those stable levels.

The substantial short-term effects of large reinforcers and lesser effects of small reinforcers are initially difficult to reconcile with the reinforcer-by-reinforcer analyses (Figure 4.11). The reinforcer-by-reinforcer analyses showed what appear to be symmetrical effects of reinforcers at the two alternatives — unlike those seen in Experiment 2a. Specific sequences of reinforcers had the same effects on preference in each condition relative to the levels at which preference began. This perhaps suggests that the effects of varying reinforcer magnitude were more molar in nature, with the tree as a whole moving towards the alternative providing the larger reinforcers, but the local effects of sequences of reinforcers remaining unchanged.

Closer inspection of the tree diagrams provides an explanation. Consider Condition 13 (7:1), in which the smaller reinforcers were arranged at the green alternative. Preference following a sequence of successive green reinforcers in this condition was similar to the stable levels of preference seen in inter-reinforcer
intervals. For comparison, sequences of three to eight successive green reinforcers the average log response ratio emitted was 0.44 (range 0.32 to 0.47). This was also the average log response ratio emitted in inter-reinforcer intervals for Bins 14 to 30 following all sequences of reinforcers.

Thus, the two analyses show that the larger reinforcers moved preference away from the stable levels shown in inter-reinforcer intervals. In contrast, the net effect of a smaller reinforcer was to leave preference unchanged at these stable levels. It is worthwhile noting that this description is an oversimplification, and misses the more local changes occurring. This effect is aided by the fact that during the brief period following the delivery of a smaller reinforcer when preference favoured the just-reinforced alternative, response rate was low (Figure 4.13). The effect is even clearer if the left-most data points in Figure 4.11 are ignored. Because a sliding window was used and the reinforcer ratio was always 1:1, these first data points consist of an average log response ratio following equal numbers of red and green reinforcers. The fact that the structure of the trees was relatively invariant across conditions was due to all sequences of reinforcers occurring with equal frequency.

To summarise, the present experiment has confirmed previous findings that changes in reinforcer magnitude exert less control over behaviour than changes in the relative frequency of reinforcement. However, the difference between the amounts of control these variables exert may be less that suggested by previous researchers (Schneider, 1973; Todorov, 1973; Todorov et al., 1984). In addition, log response ratios were found to be a linear function of the log reinforcer magnitude ratios when the sum of the reinforcer magnitudes was held constant, unlike one previous study in which the sum of the magnitudes was also varied (Davison & Hogsden, 1984). More central to the present thesis were the local effects of reinforcers. These effects were
similar in nature to those shown in rapidly changing procedures (Davison & Baum, 2000; Experiment 1 of the present thesis). Behaviour in inter-reinforcer intervals (Figure 4.12) showed evidence of both short- and longer-term effects of reinforcers, and these were also seen in reinforcer-by-reinforcer analyses (Figure 4.11). However, no evidence was provided to suggest that control became any more local as reinforcer magnitude was varied.

4.9 General Discussion

Experiments 2a and 2b have shown that the local effects of reinforcers evident in rapidly changing concurrent-schedule procedures (Davison & Baum, 2000) were not merely artifacts of the procedures themselves. Very similar effects were evident in the present experiments when a steady-state concurrent-schedule procedure was arranged, and the relative frequency or magnitude of reinforcement varied. Moreover, many similarities were evident in the effects of reinforcer frequency and reinforcer magnitude on behaviour.

For consistency, the analysis shown in Figure 4.10 for Experiment 2b in which log reinforcer effects were calculated separately for the two alternatives was repeated for Experiment 1a. This was done originally for Experiment 2b because the reinforcers delivered at the two alternatives differed. The results pose the obvious question of whether log reinforcer effect differed at the two alternatives when the relative frequency of reinforcement was varied in Experiment 2a. Figure 4.14 shows the results of this analysis for each subject in Conditions 1 (1:1), 3 (1:3), and 5 (1:9). The data from Condition 1 parallel those from Condition 12 (4:4 reinforcer magnitude ratio). A reinforcer at Lag 0 had a large effect on preference, while reinforcers beyond Lag 0 had small, generally positive effects, on current preference. Conditions
3 and 5 also parallel the results seen in Figure 4.10. Within conditions, reinforcers obtained at the higher reinforcer-rate alternative had larger more positive effects on current preference than those at the lower reinforcer-rate alternative. In the right panels, as the reinforcer ratio favoured the green alternative more, there was an increase in the values of log reinforcer effect at all lags. In the left panels, there was some evidence of a corresponding decrease in the values of log reinforcer effect. However, this was clouded by the increased variability in the estimates of log reinforcer effect in Condition 5 (1:9). This variability increased as reinforcers became less frequent. Similar to Experiment 2b, it was again the case in each condition, with the exception of Condition 1 (1:1), that log reinforcer effect beyond Lag 0 was more positive for a reinforcer obtained at the higher reinforcer-rate alternative than it was negative for a reinforcer obtained at the lower reinforcer-rate alternative. Notwithstanding the increasing variability in estimates of log reinforcer effect, this effect was significant across all conditions on sign tests (p < .05).

Behaviour in inter-reinforcer intervals was also very similar across Experiments 2a and 2b. Evidence was found for short-term effects of reinforcers in the transient movements in preference, and for longer-term effects as preference stabilised at levels that varied with the reinforcer magnitude ratios. In contrast, the tree structures differed substantially between the two experiments. These differences were exacerbated by the fact that in Experiment 2b, all sequences of reinforcers occurred with equal frequency. In Experiments 2a and 2b, large and more frequent reinforcers respectively moved preference to relatively extreme levels, and reinforcers at the other alternative resulted in preferences in the next inter-reinforcer interval that were similar to the stable levels seen in the more local analyses. The structure of the trees across the two experiments changed because the relative frequency of
Reinforcement was varied in Experiment 2a but not Experiment 2b. Preferences were more often extreme, and consequently sensitivity to reinforcement higher, in Experiment 2a when reinforcer frequency was varied.

Figure 4.14. Log reinforcer effect for each of the previous eight reinforcers plotted separately for the two alternatives ($b_1$ and $b_2$, see Equation 4.3) as a function of reinforcer lag (0 being the most recently obtained reinforcer) for each subject in Experiment 2a. Also shown are values of log $k$ for each subject.
At the most molar level of analysis (Figures 4.1 and 4.8) and the most local (Figures 4.6 and 4.12), performance was reasonably similar across the two experiments. In contrast, an intermediate, reinforcer-by-reinforcer analysis (Figures 4.5 and 4.11) showed substantial differences. This was again due to the fact that the reinforcer ratio was held constant in Experiment 2b. Thus, the occurrence of disconfirmations (smaller reinforcers as per the interpretation in Experiment 2a) was very frequent relative to Experiment 2a. This is also the most likely reason for the higher sensitivity to reinforcement values obtained in Experiment 2a. In Experiment 2a, when the reinforcer-frequency ratio was not 1:1, reinforcers at one alternative were occurred more frequently. The changes in preference following these reinforcers were larger, and longer in duration. These increased transient movements in preference occurred more often, and thus behaviour was at relatively extreme levels very often. This also meant that the disconfirmations shown in Figure 4.5 occurred very infrequently. However, in Experiment 2b the sequences of reinforcers shown in Figure 4.11 occurred with equal frequency. Thus, behaviour was equally often at the most and least extreme levels shown in Figure 4.11.

A direct comparison can be made between those conditions in Experiment 2a in which a 3:1 or 1:3 reinforcer ratio was arranged (Conditions 6, 3 and 8) and those in Experiment 2b in which a 3:1 or 1:3 reinforcer magnitude ratio was arranged (Conditions 9 and 10). This comparison shows that in addition to behaviour being at the most extreme levels more often in Experiment 2a (i.e., sequences of successive reinforcers at the richer alternative), these levels of preference were slightly more extreme than those following sequences of successive larger reinforcers. Thus, two
reasons for the higher sensitivity to reinforcer frequency values are evident in the present data.

To summarise, Experiments 2a and 2b provide evidence of both short- and longer-term effects of reinforcers. The present data suggest that these were similar in nature when either the relative frequency of reinforcement (Experiment 2a) or the relative magnitudes of reinforcement (Experiment 2b) were varied. Moreover, some evidence was presented suggesting that the effects of reinforcers were contextual, that is dependent to some extent on the frequency or magnitude of reinforcers available at the other alternative. Substantial differences between the two experiments were evident only at the reinforcer-by-reinforcer level of analysis, and these could be explained by the different frequencies with which various sequences of reinforcers occurred. Given the regularities evident at the various levels of analysis, it is clear that the lowest level of analysis presented here (Figures 4.6 and 4.12) is the most informative, when combined with an understanding of the frequency with which various events occurred (as seen also in Experiment 1). How these local effects will change when both variables are manipulated together is an important question for future research. Additionally, it is not yet clear how these effects, which are similar in steady-state data, develop. Differences in reinforcer ratios can only be detected given a relatively extended exposure to certain conditions. In contrast, a reinforcer of a larger, or smaller, magnitude delivered immediately following a response presumably does not require such exposure for differences to be detected.
Chapter V

5.1 *Summary*

The present experiments investigated the effects of reinforcers at a number of levels in two different concurrent-schedule procedures. Experiment 1 used a procedure that was introduced by Belke and Heyman (1994), and subsequently adapted by Davison and Baum (2000) to study choice behaviour in a frequently changing environment. In the canonical version of this procedure (Conditions 1, 6, and 12), seven different reinforcer ratios were presented in a random order in each session. Each reinforcer ratio was in effect for 10 consecutive reinforcer deliveries (a component). These components were separated by 10-s blackouts. Using this procedure, Davison and Baum showed that individual reinforcers had regular effects on behaviour, and they proposed a local, accumulation-based, model to account for their results. Across three experiments in the present thesis, the range of within-session changes in reinforcer ratios (Experiment 1a), the variation arranged in within-session changes in reinforcer ratios (Experiment 1b), and the symmetry of the distributions in reinforcer ratios (Experiment 1c) were all manipulated systematically. The data were analysed at a number of levels to determine what, if any, effect these manipulations had on the types of effects reported by Davison and Baum.

Experiment 2 was a standard steady-state switching-key concurrent-schedule procedure in which either the reinforcer ratio (Experiment 2a), or the reinforcer magnitude ratio (Experiment 2b), was systematically varied across conditions. Each reinforcer ratio, or reinforcer magnitude ratio, was in effect for 65 sessions. This procedure was arranged to examine whether, if the appropriate data were collected, the local effects of reinforcers shown by Davison and Baum (2000), and in
Experiment 1 of the present thesis, would be present in steady-state concurrent-schedule performance.

Experiment 1a provided evidence that the effect of a given reinforcer was changed by the context in which it was obtained (see also Mazur, 1997). Specifically, a reinforcer had a larger effect on behaviour when the range of within-session reinforcer ratios arranged was greater. This was evident at multiple levels of analysis: Sensitivity to the current-component reinforcer ratio and carryover of control between components were greater; individual reinforcers, and specific sequences of reinforcers, moved behaviour further; and transient movements in behaviour following a reinforcer delivery were both more extreme and longer in duration. In Experiment 1b, the range of within-session changes in reinforcer ratios was held constant at 27:1 to 1:27 and the reinforcer ratios in other components were varied. Similar results were observed, in that a reinforcer had a larger effect when the less extreme component reinforcer ratios were omitted. In Experiment 1c, various asymmetrical distributions of reinforcer ratios were arranged. Behaviour generally moved towards the alternative providing more frequent reinforcers, but similar local effects of reinforcers were evident.

Across all three parts of Experiment 1, disconfirmations (a reinforcer obtained from the other alternative following a sequence of successive reinforcers at one alternative, Davison & Baum, 2000) had very consistent effects. At a reinforcer-by-reinforcer level, this effect appeared very large relative to the effects of a confirmation. Inspection of behaviour within inter-reinforcer intervals showed that the effects were very large relative to preference prior to the disconfirmation. Across all conditions, preference following a disconfirmation reverted to levels that reflected
the molar or sessional reinforcer ratio. In Experiments 1a and 1b, these overall
sessional reinforcer ratios were always 1:1, but they were varied in Experiment 1c.

In conditions in which disconfirmations occurred with sufficient frequency,
sequences of reinforcers following a disconfirmation had effects similar to when the
same sequence was obtained at the beginning of a component (Figure 3.5). Thus, in
addition to returning preference to an approximation of the sessional reinforcer ratio,
a disconfirmation may also have erased some of the effects of preceding reinforcers
(see also Killeen & Smith, 1984). However, as preference reverted to a level
controlled by the sessional reinforcer ratio, any erasure of the effects of previous
reinforcers only included the cumulative effects of the preceding sequence of
successive confirming reinforcers.

The data from all three experiments were consistent with a general notion that
control was exerted over behaviour at a number of levels. In all cases, individual
reinforcers had an effect on subsequently emitted behaviour. This effect was
modified by events at other, more molar, levels. First, successive confirming
reinforcers had cumulative effects on preference. This effect was countered when a
disconfirming reinforcer was obtained which reverted preference to levels that
approximated the molar reinforcer ratio. Second, when sequences of confirming
reinforcers occurred with relatively greater frequency, these effects were again
increased or cumulative (Figures 3.6 to 3.8, 3.24 to 3.27, and 3.43 to 3.50).

Experiment 2a showed that very similar local effects of reinforcers were
evident in data obtained from a steady-state concurrent-schedule procedure, and again
that the effect on behaviour of a reinforcer was to some extent dependent on the
context in which it was obtained. At a molar level of analysis (Figure 4.1), the data
were consistent with the general findings reported previously from steady-state
concurrent-schedules procedures (for reviews, see Baum, 1979; Davison & McCarthy, 1988; Taylor & Davison, 1983; Wearden & Burgess, 1982). A more local analysis showed evidence for both short- and longer-term effects of reinforcers (Figure 4.2). The most recently obtained reinforcer had a large effect on current preference, and reinforcers back to Lag 7 also had small positive effects. Both these effects increased as the reinforcer ratio became more extreme. Residual preferences were also evident (log $k$), suggesting cumulative effects of reinforcers beyond Lag 7.

Even more local analyses showed that individual reinforcers had regular effects on subsequent preference (Figure 4.5). Again, disconfirmations had apparently very large effects, moving preference to levels similar to the stable levels of preference evident in inter-reinforcer intervals after the transient movements in preference had dissipated (Figure 4.6). These levels changed as a function of the reinforcer ratio in effect in each condition. Thus, short-term effects were evident in the transient movements in preference, and longer-term effects were evident in the changing stable levels of preference later in inter-reinforcer intervals and in the general shift in behaviour to the higher reinforcer-rate alternative.

As with Experiment 1, it seemed that the occurrence of sequences of confirming reinforcers played an important role. To examine this, the proportions of all eight-reinforcer sequences that consisted of all red or green confirming reinforcers were calculated ($p$). In the same manner as Figure 3.57, the log response ratios emitted in the inter-reinforcer intervals following these sequences were plotted as a function of the logistic transformations of these proportions ($p/(1-p)$) and are shown in Figure 5.1. Figure 5.1 shows that more extreme preferences occurred in response to the same sequence of reinforcers when that sequence of reinforcers occurred more
frequently. This relationship is very similar to that shown in Figure 3.57 for Experiment 1.

![EXPERIMENT 2A](image)

Figure 5.1. Log response ratios emitted in inter-reinforcer intervals following sequences of eight successive same-alternative reinforcers plotted as a function of the logistic transformation of the proportions of all eight-reinforcer sequences that were of that type ($p/(1-p)$).

In Experiment 2b, relative reinforcer magnitudes were varied while holding the absolute magnitude and the relative rate of reinforcement constant. These data were consistent with previous research in that sensitivity to reinforcer magnitude was lower than sensitivity to reinforcer frequency (Schneider, 1973; Todorov, 1973). Log response ratios were a linear function of log reinforcer magnitude ratios, unlike the previous study in which the presence of such a relationship was directly assessed (Davison & Hogsden, 1984). The results from Experiment 2b showed that, in steady-
state data, the effects of variations in reinforcer magnitude are manifested in a similar way to the effects of variation in the relative frequency of reinforcement. The major difference was evident in reinforcer-by-reinforcer analyses (Figure 4.11). The fact that all sequences of reinforcers of a given length occurred equally often, due to the 1:1 reinforcer ratio, meant that the tree diagrams differed. However, there was a general shift towards the alternative providing the larger reinforcers, which was evident in the tree structures as a whole, and in behaviour during inter-reinforcer intervals (Figure 4.12). Smaller reinforcers resulted in preferences similar to the stable levels evident later in inter-reinforcer intervals in much the same way that leaner-alternative reinforcers did in Experiment 2a. When values of log reinforcer effect were calculated separately for the two alternatives, further evidence for the idea that the effects of reinforcers are dependent on the context in which they are obtained was provided. Log reinforcer effect was larger at the alternative providing the larger reinforcers, and often became negative at the other alternative. Similar effects were evident in the data from Experiment 2a when they were examined in the same manner. However, as the occurrence of reinforcers at one alternative became less frequent, estimates of log reinforcer effect became variable, rendering comparisons difficult. As outlined above, it is possible that the changes in log reinforcer effect for reinforcers at the two alternatives were in part driven by the relative reinforcer magnitudes rather than the absolute magnitudes at the two alternatives. This could be examined more thoroughly by arranging a series of conditions in which the reinforcer magnitude was held constant at one alternative and varied at the other (as per Davison & Hogsden, 1984).
5.2 *Generalized matching*

The present research has confirmed the GML’s utility as an excellent description of behaviour in a variety of choice situations. In Experiment 1, analyses based on the GML showed how the previous-component reinforcer ratio affected current behaviour, and how control by the current-component reinforcer ratio developed with successive reinforcer deliveries (see Figures 3.3, 3.22, and 3.38). Previously, it has been shown that the GML described well data obtained in Experiment 1a (Landon, 1999). Thus, the GML remains useful as a descriptive tool, even in atypical procedures in which contingencies change very rapidly.

In Experiment 2a, at a molar level of analysis, the data were similar to those obtained previously using steady-state concurrent-schedule procedures (Baum, 1979; Davison & McCarthy, 1988; Taylor & Davison, 1983; Wearden & Burgess, 1982). Values of sensitivity to reinforcement were generally a little higher than those reported previously, but this might have been expected given that 65 sessions were arranged in each condition (Todorov et al., 1983). In Experiment 2b, the GML again described the data well when reinforcer magnitude was varied across the two alternatives. These data were once again similar to those reported in previous experiments, although values of sensitivity to reinforcer magnitude were higher than in previous research (c.f., Schneider, 1973; Todorov, 1973; Todorov et al, 1984). It should be noted, however, that this was the first study that systematically varied relative reinforcer magnitude with the overall reinforcer magnitude held constant, and used least-squares linear regression to estimate sensitivity to reinforcer magnitude.

The present research does, however, question the commonly held assumption that reinforcers aggregated over large periods of time control behaviour. Both of the present experiments suggest that such a view is simplistic, and misses much regularity.
evident in behaviour at lower levels of analysis. Thus, some re-evaluation of how concurrent-schedule performance is viewed is required. At this stage, it seems that the variables controlling behaviour operate at a number of levels ranging from the location of the previous reinforcer, through the preceding sequence of reinforcers (if they were successive confirmations), to much larger long-term aggregations of reinforcers. Neither a completely molar approach, nor a completely local one, satisfactorily captures all aspects of performance in either of the present sets of experiments. These problems, in addition to those shown previously (e.g., Alsop & Elliffe, 1986; Davison, 1988; Davison & Hogsden, 1984; Davison & Jones, 1998; Elliffe & Alsop, 1996; Logue & Chavarro, 1987) mean that the GML is not tenable as an explanatory model of choice behaviour.

5.3 Local models of performance.

No formal attempt to fit any of the models outlined in Chapter 2 to the present data has been made. At this stage, it seems that the best approach is to focus on the collection of detailed data rather than the development of quantitative models to describe or explain the data that have been collected so far. Each of the models outlined had failed to account for at least one existing data set, with the exception of the Davison and Baum (2000) accumulator model. That model, however, failed to predict the results of Experiment 1a of the present thesis with a single set of parameter values. Moreover, few existing models can easily integrate the effects of reinforcer magnitude, and as yet the interaction between reinforcer frequency and reinforcer magnitude has not been examined at lower levels of analysis, nor have variables such as reinforcer delay and response arduousness. Once detailed data have been collected and examined following variations of at least some of these parameters, a better idea
of some of the requirements for a more complete model of concurrent-schedule performance can be identified.

The present research provides some indication of the features that will be required by such a model, but many issues such as those outlined above remain to be addressed. It seems clear that a model of concurrent-schedule performance must involve more than one process (see, for example, Davis & Staddon, 1990; Landon & Davison, 2001). Behaviour is, to some extent, sensitive to local reinforcer contingencies, as has been shown throughout the present thesis. Any quantitative model must predict the transient movements in preference following a reinforcer delivery. However, these transient movements were clearly affected by more molar contingencies: They were longer following a reinforcer obtained at the higher reinforcer-rate alternative; and successive reinforcers obtained at that alternative had cumulative effects following a transition (Experiment 1). The local process allowed preference to become relatively extreme following a sequence of confirming reinforcers. In both experiments, however, a disconfirming reinforcer reverted preference to a level that approximated the molar reinforcer ratio. This further suggests that any local control was limited by more molar contingencies, and that an updating of the more molar process and resetting of the more local one perhaps occurred when a disconfirming reinforcer was obtained. How extreme preference became following a sequence of confirming reinforcers was also influenced by more molar factors; as Figures 3.57 and 5.1 showed, preference became more extreme following the same sequence of reinforcers as their frequency increased. In addition, the documented effect of overall reinforcer rate (Alsop & Elliffe, 1988; Davison & Baum, 2000; Dreyfus, 1991; Elliffe & Alsop, 1996) has to be accommodated. It remains possible that overall reinforcer magnitude has a similar effect. This is
suggested by the more extreme preferences evident as overall reinforcer magnitude
was increased (Davison & Hogsden, 1984), and the linear relationship evident
between log response ratios and log reinforcer magnitude ratios when overall
reinforcer magnitude was held constant (Figure 4.8).

Thus, it seems that more than a single process is required to account for
behaviour. If the accumulation approach (Davis et al. 1993; Davison & Baum, 2000)
is to be pursued, it is likely that at least three separate but interacting accumulators
would be required: A short-term process tracking each successive reinforcer delivery
and perhaps being re-set when sequences of confirming reinforcers are broken; a
medium-term process perhaps updated when sequences of confirming reinforcers are
broken; and, an even longer-term process containing very large aggregations of
reinforcers. However, exactly how the effects of reinforcer magnitude would be
accommodated by such an approach is not yet clear. A more thorough investigation
of the effects of variations in reinforcer magnitude using the Belke and Heyman
(1994) procedure would be useful in this regard.

It remains possible that the processes in operation are more dynamic or fluid in
nature than can be achieved by proposing the existence of discrete processes operating
at different levels. To some extent, this is evident in the investigation of the effects of
reinforcer magnitude presented here (Experiment 2b). Control by reinforcer
magnitude seemed very similar to control by reinforcer frequency when GML
analyses and behaviour in inter-reinforcer intervals were examined. However,
reinforcer-by-reinforcer analyses showed that the effects of reinforcer rates and
reinforcer magnitudes differed. These inconsistencies were understandable, but
highlight the differences between the two independent variables and how results can
appear similar at one level of analysis, but very different at another.
It is possible that the effects of reinforcer magnitude were not due to the same molar processes as the effects of differences in reinforcer frequency. In both cases the effects of a given reinforcer were dependent on the context in which they were obtained. When reinforcer frequency was varied, a reinforcer was obtained in the context of more or less frequent reinforcers spaced over time at the other alternative. When reinforcer magnitude was varied, larger or smaller reinforcers being available at the other alternative provided the context. Thus, an estimate of relative reinforcer magnitude would not necessarily require the same extended exposure to a particular condition, as would an estimate of relative frequency of reinforcement. Therefore, control by reinforcer magnitude might be expected to develop in a different manner from control by reinforcer frequency.

To reiterate, it would be premature at this stage to focus on the development of a quantitative model to account for the present results. A return to fundamental examinations of concurrent-schedule performance is recommended, coupled with further detailed data collection. What is clear is that any model of concurrent-schedule performance must take account of both short- and long-term effects of individual reinforcers and aggregations of reinforcers by some integration of processes that operate at multiple levels.

5.4 Levels of analysis

The present experiments did not directly try to identify the appropriate level of analysis to study behaviour. However, as Nevin (1984) suggested, the most satisfactory answer to that question remains Skinner's (1938) suggestion that the best level is that at which the results are orderly and repeatable. So far, that level has been at a molar level. Nevin argued that the "possibility that molar relations of this sort
may prove to be derivative from more local processes does nothing to diminish their value as ways to summarise and integrate data” (p. 431). This view remains true, but the present thesis has also demonstrated orderly and repeatable results at lower levels of analysis. It could, therefore, be similarly argued that there is just as much if not more value in using more local analyses to summarise and integrate data.

It is still possible that regularities could be evident at even lower levels of analysis, or when the data are examined in a different way. Some researchers have suggested closer inspection of visits or residence times (Baum et al., 1999), others have suggested the possible emergence of new response classes that would conform to matching (e.g., Herrnstein, 1982; Heyman & Tanz, 1995). The latter might exist, but the analyses of behaviour in inter-reinforcer intervals presented here question the suggestion that they always conform to matching. It is either the case that soon after reinforcement these response classes overmatch, and then later in inter-reinforcer intervals they undermatch, or, that the response class changes with time since reinforcement. It remains, however, that despite the orderly results at these varying levels of analysis, no single analysis or process is likely to be sufficient to account for all aspects of concurrent-schedule performance. Such an account requires integration of effects occurring at multiple levels.

5.5 General Discussion

Experiment 1 extended on research reported by Davison and Baum (2000), and Experiment 2 showed that the local effects of reinforcers identified by Davison and Baum were also present steady-state concurrent-schedule performance. Previously, researchers investigating behaviour in changeable conditions had been limited to examining behaviour when reinforcer ratios were changed between sessions
either every few sessions (Davison & Hunter, 1979), or every session (Hunter & Davison, 1985; Schofield & Davison, 1997). Others had investigated behaviour when a single change in reinforcer ratios occurred within a session that followed several sessions in which the reinforcer ratio was unchanged (Bailey & Mazur, 1990; Mazur, 1992; 1995; 1996; 1997; Mazur & Ratti, 1991). Dreyfus (1991) arranged more than one change in reinforcer ratios per session, but interpretation of his results is clouded by the fact that those changes always occurred at the same time during a session, opening the possibility that to some degree behaviour could have come under the control of elapsed session-time.

Taken together, the research suggested that regular and quantifiable changes occur in behaviour during transitions between steady states. Additionally, previous reinforcers, both those obtained in previous sessions and those obtained in the present session, exert some control over behaviour. The degree of control by previous reinforcer ratios is affected by the frequency of environmental change. For instance, Davison and Hunter (1979) found control exerted by a previous session’s reinforcer ratio three or four sessions after a change when the reinforcer ratio was changed every six sessions. At the other extreme, Davison and Baum (2000) found control by the previous-component reinforcer ratio five or six reinforcers into a new component, and no effect of component length on behaviour. The size of a change in reinforcer ratios seemed to have no effect on the rate of behavioural change (Schofield & Davison, 1997). In contrast, a higher overall rate of reinforcement consistently resulted in behaviour changing more quickly (Davison & Baum, 2000; Dreyfus, 1991; Mazur, 1997).

Consistent with Davison and Baum (2000), the present thesis showed that individual reinforcers had regular effects on behaviour. However, like Mazur (1997),
the present data suggested that the effect of an individual reinforcer was dependent on the context in which it was obtained. In Experiment 1, the effect was greater when the range of reinforcer ratios was greater, it was also greater when the range of reinforcer ratios was the same but there was less variation in them. At a lower level of analysis, the effect was larger if that reinforcer followed a sequence of reinforcers obtained at the same alternative. As has been discussed, these results implied that control was more complex than could be achieved by proposing the existence of a single process operating at one level. Nonetheless, the present research demonstrated again that orderly and quantifiable changes occur in behaviour during periods of transition. Moreover, that when sufficient data are collected, orderly and quantifiable effects of individual reinforcers and sequences of reinforcers were also evident.

The data from Experiment 1 suggest that some molar control over responding was present in addition to the local effects of reinforcers. Analyses at different levels provided converging evidence suggesting that this may have been driven by the changing frequencies of sequences of successive confirming reinforcers. There are many ways of differentiating between the different reinforcer ratio arrangements used in Experiment 1 (and in Experiment 2). But the regularities evident in reinforcer-by-reinforcer analyses (Figures 3.4, 3.5, 3.23, 3.39, 3.40, and 3.41), the cumulative effects of successive confirming reinforcers on behaviour seen in inter-reinforcer intervals (e.g., Figures 3.24 to 3.26), and the regularity evident at a more molar level (Figure 3.57) suggested that the occurrence of these sequences was central in producing the present results, and warrant further direct investigation to ascertain their importance in concurrent-schedule performance. Additionally, Experiment 1c showed that when the distributions of arranged reinforcer ratios were asymmetrical (with or without a range of variation), there was a general movement in behaviour
towards the higher reinforcer-rate alternative. This effect too was probably driven by
the high frequency of sequences of successive confirming reinforcers in those
conditions (see Figure 3.57).

Experiment 2a showed that very similar local effects of reinforcers were also
present in steady-state concurrent-schedule performance. The major effects of
individual reinforcers seen in Experiment 1 were also evident in Experiment 2a, as
was the regularity of behaviour with respect to sequences of successive confirmations
(see Figure 5.1). Indeed, Conditions 25 to 28 of Experiment 1c produced data very
similar to those from Experiment 2a. Thus, the approach taken to studying behaviour
by Davison and Baum (2000), and in Experiment 1, was validated as useful in
identifying processes present in standard steady-state behaviour. The degree of
similarity between behaviour in the two procedures was great, and it seems that in
addition to providing data on how steady-state preferences develop, the Belke and
Heyman (1994) procedure might be a viable alternative to steady-state procedures in
some situations. Thus, in such cases the time frame required for data collection could
be greatly reduced.

As noted earlier, Davison and Baum (2002) reported a drift towards
indifference during unsignaled periods of extinction. Myerson and Hale (1988)
investigated the transition between concurrent VI VI schedules and unsignaled
extinction. They showed that preference remained unchanged over six to twelve
sessions of extinction. In contrast, Nevin (1969) reported a drift towards indifference
over ten sessions of unsignaled extinction in a discrete-trials concurrent-schedule
procedure. Myerson and Hale suggested the two procedures were fundamentally
different in that a discrete-trials procedure by its very nature includes periods of
signaled extinction. Davison and Baum, thus, reasoned that the blackouts they
arranged between components were also periods of unsignaled extinction, and thus their results were consistent with Myerson and Hale’s explanation, and both previous sets of data. Moreover, as would be expected, Davison and Baum also observed a drift towards indifference in inter-reinforcer intervals (as was the case here in Experiments 1a and 1b during inter-reinforcer intervals). However, Experiments 1c and 2a suggest another possibility. The drift to indifference reported by Davison and Baum could have been a result of their sessional reinforcer ratio having always been 1:1. That is, it could be due to control by the sessional reinforcer ratio, and thus consistent with Myerson and Hale, and the present experiments. A simple replication of their procedure with asymmetrical distributions of reinforcer ratios (as per Experiment 1c) would address this question.

If the drift towards indifference reported by Davison and Baum (2002) and evident in Experiments 1a and 1b of the present thesis were due to the sessional reinforcer ratio being 1:1, the question remains; why did Nevin’s (1969) results differ? The present research, particularly with respect to the role of sequences of confirming reinforcers, suggests his result could have been due to his schedule arrangement. Nevin used independent concurrent VI 1-min VI 3-min schedules. The VI 1-min schedule consisted of eleven arithmetically spaced intervals from 10 s to 110 s. The VI 3-min schedule consisted of nine arithmetically spaced intervals from 10 s to 350 s. Nevin showed that the obtained reinforcer ratio closely approximated the arranged one. The nature of his schedules meant they would have consisted of many fewer sequences of successive confirming reinforcers than Experiment 2a and the others considered (Myerson and Hale, 1988 did not specify how their schedules were constructed). A simulation of Nevin’s procedure was arranged using the same arithmetic intervals, but using variable-time schedules. This provided a reasonable
approximation of Nevin’s actual procedure, given the close approximation to the arranged reinforcer ratio he demonstrated (see Nevin’s Table 1). In the simulation, the intervals were selected randomly without replacement from a list, rather than being presented repeatedly in the same order.

**SUCCESSIVE REINFORCERS AT RICHER ALTERNATIVE**

Figure 5.2. The proportions of all possible sequences of reinforcers of one to eight reinforcers in length that were sequences of successive confirming reinforcers obtained at the alternative providing the higher rate of reinforcement in Condition 3 (1:3) of Experiment 2a, and a simulation of Nevin’s (1969) procedure.

Figure 5.2 shows the proportions of all sequences of various lengths that were sequences of successive confirming reinforcers in the simulation of Nevin’s (1969) procedure, and the equivalent condition from Experiment 2a (Condition 3, 1:3). It is evident that the present procedure, in which a single schedule was used and reinforcers were assigned probabilistically to the alternatives, resulted in a much higher frequency of sequences of confirming reinforcers. The present thesis has established that preferences differ as the frequency of these sequences changes.
(Figures 3.57 and 5.1). It is therefore plausible that Nevin’s result could have differed due to the lower frequency with which these sequences occurred. Moreover, the present results, and this analysis, suggest that closer attention should be paid to the distributions of sequences of reinforcers that occur given different concurrent-schedule procedures. If the same reinforcer ratio is arranged, but a higher frequency of sequences of confirming reinforcers occur, it would be expected that sensitivity to reinforcement would increase because preferences will be both more extreme and at those more extreme levels more often, when such sequences occur more frequently. Indeed, the schedule arrangement used in Experiment 2a here could have contributed to the values of sensitivity to reinforcement that were slightly higher than those commonly reported (Baum, 1979; Taylor & Davison, 1983; Wearden & Burgess, 1982).

The suggestion above might also be useful in interpreting the differing results reported by Alsop and Elliffe (1988) and Elliffe and Alsop (1996). Alsop and Elliffe showed sensitivity to reinforcement increased monotonically when separate concurrent arithmetic schedules were used and the overall rate of reinforcement was increased. Elliffe and Alsop found a more complex relationship when a single exponential schedule was used, and reinforcers were allocated probabilistically to the two alternatives (as with Experiment 2 of the present thesis), but they found generally higher values of sensitivity to reinforcement.

Elliffe and Alsop (1996) reasoned that this latter effect might be due to arithmetic schedules placing limits on the shortest possible inter-reinforcer intervals, while the exponential schedules were limited only by the sampling interval (typically 1 s). To examine this, they arranged hybrid exponential schedules in which the sampling interval was 1/12 of the mean interval, thus the schedules were exponential
but contained this particular feature of arithmetic schedules. This arrangement returned to using two separate schedules to arrange reinforcers, and sensitivity values were obtained that were lower than those obtained using exponential schedules. Clearly this suggests that the shortest inter-reinforcer intervals were important. However, by returning to using two separate schedules a lower frequency of sequences of successive confirming reinforcers would have occurred. The present data suggest that this too could have resulted in lowered values of sensitivity to reinforcement.

Where it is possible, it might be useful to review concurrent-schedule research re-classifying procedures in terms of the frequency with which they arranged sequences of confirming reinforcers. The present thesis suggests that these sequences are important in determining the short- and longer-term effects of reinforcers in concurrent schedules. Thus, classifying procedures in terms of a molar measure such as the relative frequency of reinforcement might be less than ideal. As Figure 5.2 shows, two procedures in which the same relative frequencies of reinforcement were arranged can differ substantially when examined at more local levels. These differences might to some extent provide a viable means of holding the reinforcer ratio constant, and varying the frequency of sequences of successive confirming reinforcers. However, there seems no obvious means of probabilistically allocating reinforcers from a single schedule (exponential or arithmetic), and arranging a difference in the shortest possible inter-reinforcer intervals. Clearly though, a systematic manipulation of the frequencies of sequences of confirming reinforcers with the relative frequency of reinforcement held constant would be useful in examining more closely the role of such sequences in determining the short- and longer-term effects of reinforcers.
5.6 Conclusions

The present research has confirmed that the frequently changing procedure used by Davison and Baum (2000) (see Belke & Heyman, 1994) provides a means for examining behaviour at a resolution not previously possible. The local effects of reinforcers shown by Davison and Baum were found to change as the distribution of within-session changes in reinforcer ratios was manipulated. This research extended the earlier work described in Chapter 2 that had examined behaviour in conditions which varied more frequently than traditional steady-state approaches. That research was largely limited to single within- or between-session changes in reinforcer ratios. Additionally, it was shown that the local effects of reinforcers in this procedure were also affected by more molar contingencies.

These findings led to the obvious question of whether they were unique to frequently changing procedures, or are also present in conventional steady-state concurrent-schedule performance. Experiment 2 showed that the local effects of reinforcers, and the interacting control by more molar contingencies, were indeed similar to those seen in a standard steady-state procedure. Thus, the present thesis suggests a need for some re-evaluation of how concurrent-schedule performance is viewed. The assumption that behaviour is solely controlled by long-term aggregations of reinforcers can be dismissed. However, this must be tempered with the knowledge that long-term aggregations of reinforcers remain important in accounting for concurrent-schedule performance, as do individual reinforcers and specific sequences of reinforcers.

The research outlined in Chapter 2 suggested that as environments changed more quickly behavioural control became more local in nature. As discussed above, it had been generally assumed that in steady-state concurrent schedules behaviour was
controlled by large aggregations of reinforcers. Davison and Hunter (1979) showed that when a change in reinforcer ratios was arranged every six sessions, control by the previous reinforcer ratio was evident three or four sessions after the change. Schofield and Davison (1997) showed that when the changes occurred every session, and sufficient training was given, no control was evident by the previous-session’s reinforcer ratio. Davison and Baum (2000) apparently identified a limit to these changes when they found no effect of component length using the same procedure as used in Experiment 1 here. However, Experiment 1 of the present thesis showed that the effects of individual reinforcers on behaviour did change when the distributions of within-session changes in reinforcer ratios changed. In addition, Experiment 1 showed evidence of some longer-term aggregations of reinforcers exerting control over behaviour in a frequently changing procedure. Moreover, Experiment 2a showed that steady-state concurrent-schedule performance showed clear evidence of both short- and long-term effects of reinforcers in a steady-state procedure. Thus, it seems that, irrespective of the procedure used, both short- and longer-term effects of reinforcers and aggregations of reinforcers can be identified when the appropriate data are collected.

The present research suggests that sequences of confirming reinforcers may be central, and that longer-term aggregations or estimates might be updated following the delivery of a disconfirming reinforcer. This could be commensurate to some extent with the idea that reinforcers themselves might acquire discriminative properties (Chapter 2). It should be possible to alter the frequency with which sequences of confirming reinforcers occur independently (to some extent) of the reinforcer ratio (see previous section). Such a procedure would examine with more precision the role of sequences of confirming reinforcers. Across all experiments in the present thesis,
there was evidence of control exerted over behaviour at uncommonly long inter-
reinforcer intervals by the molar, or sessional, reinforcer ratio. Evidence of longer-
term control has been reported previously at more molar levels of analysis when
behaviour following a transition was examined in procedures that changed less
frequently than Experiment 1 (e.g., Davison & Hunter, 1979; Hunter & Davison 1985;
Mazur, 1995; 1996; 1997), but not at such a local level. The suggestion here is that
this longer-term control might also have been driven by the frequency of sequences of
confirming reinforcers. Thus, if this frequency can be varied independently of the
reinforcer ratio, differences should be evident in the stable levels of behaviour in long
inter-reinforcer intervals.

Given that some reasonably basic assumptions about the variables controlling
choice behaviour in concurrent schedules have been questioned by the present
research, there is a need to continue with the approach exemplified in Experiment 2.
More detailed data should be collected using steady-state concurrent-schedule
procedures with a variety of schedule arrangements used. The present results are
generally consistent with Mazur's (1997) conclusion that the effect of an individual
reinforcer is dependent on the context in which it is obtained. However, a more
precise definition of exactly what constitutes this context is required. To investigate
the possibility that the effects of reinforcers are contextual, simple procedures could
be arranged in which the reinforcer rate or magnitude at one alternative is held
constant, while the rate or magnitude of reinforcement is varied at the other
alternative. The context may differ between reinforcer rate and reinforcer magnitude.
With respect to reinforcer magnitude, it is reasonably straightforward as little or no
sampling over a larger time period is required. Provided discrimination is accurate, a
reinforcer obtained at each alternative may be sufficient for the context to be apparent.
However, a reinforcer at one alternative can only be more frequent in the context of reinforcers at the other alternative when both are sampled over some time frame. Thus, the effect of local variations must be examined closely, and again arranging different frequencies of runs of confirming reinforcers with the same reinforcer ratio would be a useful way of investigating this.

Additionally, as has been suggested earlier, detailed data should be collected when both reinforcer frequency and reinforcer magnitude are manipulated. As more data are collected, the focus should move to other independent variables such as delay of reinforcement and response arduousness. Unfortunately, such detailed data collection is a slow process, and somewhat repetitive given the extensive history of investigating concurrent-schedule performance. However, current technology means that data can be examined at lower levels than has been previously possible. Future investigations of this type may redefine more precisely how concurrent-schedule performance should be viewed, and contribute to a better understanding of the variables that control behaviour and how they interact.
REFERENCES


