CHOICE IN A VARIABLE ENVIRONMENT: DOES EVERY REINFORCER COUNT?

Andrew M. Rodewald

A Thesis Submitted to the University of North Carolina Wilmington in Partial Fulfillment of the Requirements for the Degree of Master of Arts

Department of Psychology
University of North Carolina Wilmington
2009

Approved by

Advisory Committee

Christine E. Hughes, PhD. Carol A Pilgrim, PhD.

D. Kim Sawrey, PhD. Raymond C. Pitts, PhD.
Chair

Accepted by

Dean, Graduate School
TABLE OF CONTENTS

ABSTRACT..................................................................................................................... iii

ACKNOWLEDGMENTS ................................................................................................... v

DEDICATION .................................................................................................................. vi

LIST OF TABLES .......................................................................................................... vii

LIST OF FIGURES ........................................................................................................ viii

INTRODUCTION ........................................................................................................... 1

Choice and Concurrent Scheduling ............................................................................. 1

Some Early Work on Concurrent-Schedules .............................................................. 2

Concurrent VI Schedules and Matching .................................................................... 4

Choice in Transition ..................................................................................................... 10

Purpose of Present Study ............................................................................................. 18

METHOD ...................................................................................................................... 19

Subjects ....................................................................................................................... 19

Apparatus ..................................................................................................................... 20

Procedure ..................................................................................................................... 20

Data Analysis ............................................................................................................... 22

RESULTS ..................................................................................................................... 24

DISCUSSION ............................................................................................................... 66

PIEs and Molar Analysis .............................................................................................. 69

Experimental Data ..................................................................................................... 73

Limitations .................................................................................................................... 75

Conclusions ................................................................................................................. 77
References ........................................................................................................................................... 79
ABSTRACT

Four pigeons were trained to respond on a concurrent schedule of reinforcement in which reinforcement ratios for responding on either option changed seven times during the session in a random sequence. Each of these components lasted for 10 reinforcers and was separated by a 10 second blackout period. Data were first analyzed in blocks of 35 sessions (sessions 15-50). In these blocks, sensitivity of responding to the current reinforcer ratio in effect was calculated for each pigeon. Further, an analysis to examine the effects on responding on consecutive reinforcers and the effect of reinforcement obtained via one option after receiving more than one reinforcer on the other. An analysis of responding after a reinforcer was delivered was conducted as well, and a lag analysis of sensitivity to reinforcer rate was conducted on a component by component basis.

These same analyses were conducted for blocks of 10 sessions. The results of the analysis at different levels of aggregations were similar; sensitivity to reinforcer ratio increased as more reinforcers were delivered within a component, and responding became more disparate as more consecutive reinforcers were delivered via one option, but response ratios shifted to ratios similar to those seen before a reinforcer had been delivered with the delivery of a single reinforcer via the alternative option. Further, data were similar in other aspects; analyses of responding after a reinforcer tended to occur on the option that had just delivered reinforcement, and then quickly drop towards indifference. As per the lag analysis sensitivity was highest for the component currently in effect and low for previous components. Data from sessions 1-15 were analyzed to examine acquisition of behavior in this preparation and revealed acquisition of this behavior occurring early, some response patterns in as many as 10 sessions.
ACKNOWLEDGEMENT

I would like to thank my mentor, Dr. Raymond Pitts, for his guidance throughout my time at UNCW. His attention to detail and thoughtful comments have helped to foster better scientific behavior, and for that I am indebted to him. I would also like to thank my thesis committee, Drs. Christine Hughes, Carol Pilgrim and D. Kim Sawrey for their encouragement and comments through the creation of this manuscript.
DEDICATION

I would like to dedicate this manuscript to my father and mother, Dennis and Judith Rodewald. Their support throughout my many, many years of college means more to me than they may ever know.
<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Individual Subject Sensitivity Parameter (A), Bias and Coefficient of Determination ($R^2$) Values on a Reinforcer by Reinforcer Basis in Blocks of 10 Sessions</td>
<td>40</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Hypothetical subject data. Plotted are the log response ratios on each two</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>alternatives (subscript 1 and 2) as a function of their respective log</td>
<td></td>
</tr>
<tr>
<td></td>
<td>reinforcer ratios. Line a represents matching, lines B and C represent</td>
<td></td>
</tr>
<tr>
<td></td>
<td>undermatching and overmatching respectively and lines D and E represent</td>
<td></td>
</tr>
<tr>
<td></td>
<td>bias for the first alternative and second alternative respectively</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Subject 280. Log response ratio (Left to Right) graphed as a function of Log</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>reinforcer ratio (Left to Right). Individual panels denote different</td>
<td></td>
</tr>
<tr>
<td></td>
<td>successive reinforcers within a component</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Subject 8418. Log response ratio (Left to Right) graphed as a function of Log</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>reinforcer ratio (Left to Right). Individual panels denote different</td>
<td></td>
</tr>
<tr>
<td></td>
<td>successive reinforcers within a component</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Subject 17560. Log response ratio (Left to Right) graphed as a function of Log</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>reinforcer ratio (Left to Right). Individual panels denote different</td>
<td></td>
</tr>
<tr>
<td></td>
<td>successive reinforcers within a component</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Subject 49889. Log response ratio (Left to Right) graphed as a function of Log</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>reinforcer ratio (Left to Right). Individual panels denote different</td>
<td></td>
</tr>
<tr>
<td></td>
<td>successive reinforcers within a component</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Preference pulses for each subject. Log response ratios for just productive</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>alternative (P) and not just productive alternatives (N) graphed as a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>function of responses following a reinforcer. Data taken from sessions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15-50</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Log response ratios (left to right) graphed as a function of reinforcers</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>delivered during a component. Filled circles connected by solid lines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>indicate consecutive reinforcers obtained via the same option (“</td>
<td></td>
</tr>
<tr>
<td></td>
<td>confirmations”), and open circles connected to the filled circles by</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dashed lines denote reinforcers delivered by an alternative after</td>
<td></td>
</tr>
<tr>
<td></td>
<td>consecutive reinforcers had been delivered by the other option (“</td>
<td></td>
</tr>
<tr>
<td></td>
<td>disconfirmations”)</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Sensitivity to reinforcement rate graphed as a function of session lag</td>
<td>35</td>
</tr>
<tr>
<td>9.</td>
<td>Sensitivity to reinforcer rate graphed as a function of reinforcers</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>delivered in components for the first 50 sessions</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Sensitivity to reinforcer rate graphed as a function of reinforcers</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>delivered in components for sessions 51-100</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Individual subject data, proportion of just productive alternatives to the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>total amount of responses graphed as a function of responses after</td>
<td></td>
</tr>
<tr>
<td></td>
<td>reinforcement for</td>
<td></td>
</tr>
</tbody>
</table>
the first 50 sessions ........................................................................................................46

12. Individual subject data, proportion of just productive alternatives to the total amount of responses graphed as a function of responses after reinforcement for sessions 51-100 ........................................................................................................47

13. Log response ratios (left to right) for subject 280 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 1-50 ..........50

14. Log response ratios (left to right) for subject 280 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 51-100 ......51

15. Log response ratios (left to right) for subject 8418 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 1-50 ........................................................................................................52

16. Log response ratios (left to right) for subject 8418 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 51-100 ........................................................................................................53

17. Log response ratios (left to right) for subject 17560 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 1-50 ........................................................................................................54

18. Log response ratios (left to right) for subject 17560 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 51-100 ........................................................................................................55

19. Log response ratios (left to right) for subject 49889 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 1-50 ........................................................................................................56

20. Log response ratios (left to right) for subject 49889 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 51-100 ........................................................................................................57

21. Individual subject data (280), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block .........................58

22. Individual subject data (280), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block .........................59

23. Individual subject data (8418), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block .........................60

24. Individual subject data (8418), sensitivity to reinforcer ratio graphed as a function
of session lag. Each panel represents a different ten session block..........................61

25. Individual subject data (17560), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block..........................62

26. Individual subject data (17560), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block..........................63

27. Individual subject data (49889), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block..........................64

28. Individual subject data (49889), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block..........................65
INTRODUCTION

Choice and Concurrent Scheduling

Within a behavior-analytic paradigm, scientists focus on relations between an organism’s environment and its behavior. Of particular interest are relations between behavior and consequences, and how these relations affect the future occurrence of behavior. In a typical environment, an organism almost always has a number of behavioral options available that provide different consequences. Conceptualized in such a manner, an argument could be made that a cornerstone of studying behavior is the study of “choice” (i.e., behavioral allocation to available alternatives).

To study factors that control behavior when multiple options are available, a common preparation is a concurrent-schedule (conc) of reinforcement (see Ferster & Skinner, 1957). A typical concurrent-schedule arrangement consists of two response options available simultaneously. A separate schedule is arranged for each option, and the associated consequence occurs when the given contingency is satisfied. For example, an operant-conditioning chamber built for a rat could have two levers available simultaneously, and the rat can respond on either; each option is associated with a schedule of reinforcement and/or punishment.

Two-response concurrent schedules have been used extensively to study different factors controlling behavior allocation in this preparation (see Catania, 1966; Davison & McCarthy, 1988; deVilliers, 1977). Further, it is an effective and convenient way of examining aspects of reinforcement that dictate responding for one option over another.

Study of behavior allocation is important because of the relative ease that various aspects of reinforcement can be manipulated and is also helpful in describing behavior in non-laboratory
analogs. For example, a person may be faced with the option of either watching television or listening to music. Both options can be emitted freely, and one can alternate between the two options, just as in the laboratory preparation (see McDowell, 1988 for more examples of concurrent schedules in naturalistic settings). Separate reinforcers are associated with both alternatives and it may be difficult or impossible to obtain them simultaneously. There are contingencies of reinforcement associated with both options, but at a given moment behavior will be allocated towards one or the other. There likely are many factors controlling behavioral allocation in such circumstances, but many, if not all, aspects of reinforcer contingencies can be investigated using this basic concurrent-schedule preparation.

Some Early Work on Concurrent-Schedules

Two of the goals of some of early work using concurrent schedules were to determine if characteristic performance maintained by a given schedule in a concurrent arrangement would be similar to that typically obtained when the schedule was presented alone, and to characterize interactions between the schedules (e.g., Catania, 1966; Ferster & Skinner, 1957; Findley, 1958; 1962). A major factor determining the degree that performance on one option in a concurrent schedule is affected by the contingencies associated with the other schedule is the degree of compatibility of the operants (Catania, 1966). For example, Ferster (1957) reported a study in which chimpanzees were required to respond on a conc fixed-ratio (FR) 120 variable-interval (VI) 4-min schedule. An FR schedule requires a certain number of responses to be made for reinforcement. In an interval schedule, a response produces the scheduled reinforcer after a given interval of time has passed. In a VI schedule, the duration of time that is required to pass varies from reinforcer to reinforcer. These schedules were selected because one typically produces higher rates of responding (FR120) and the other typically produces lower rates of
responding (VI 4-min). Each key was close enough in proximity that the chimpanzee could respond on both simultaneously. That is, they were compatible concurrent operants. Ferster found that because the animal could respond on both options simultaneously, there was an interaction of both schedules. Despite one schedule encouraging rapid responding and the other slower responding, responses rates were very similar. An issue associated with compatible operants is described as a special case of superstition; that is, the accidental correlation of a response with the contingency associated with the other option (Catania, 1966). This can be remedied by making the responses incompatible; that is, making it impossible to emit both responses simultaneously (e.g., by moving the options farther apart). For example, a pigeon in an operant conditioning chamber with two separate response keys available is a case of incompatible concurrent operants.

Even with incompatible concurrent operants, however, the contingencies associated with one option can affect responding on the other (e.g., Catania, 1966; Herrnstein, 1961). To isolate the contingencies associated with their respective responses further, it is typical to use a changeover delay (COD; e.g., Herrnstein 1961, Shull & Pliskoff, 1967). When a COD is in effect, a switch from one option to another option cannot be immediately reinforced. This temporal separation is advantageous as it can minimize “superstitious” switching between response options. Using a COD can aid in isolating the contingencies associated with their respective keys.

Another method of isolating control of behavior on one option from the contingencies associated with the other is to use a switching, or Findley, procedure. In this procedure, an experimental subject (e.g., pigeon) has two response options (e.g., keys) at its disposal; responding on one key counts toward programmed contingencies associated with it, whereas
responding on the other (switching) key changes between contingencies (Findley, 1958). For example, a conc VI 30-s VI 60-s schedule could be implemented with a green light associated with the former and a red light associated with the latter. The change-over key may be illuminated another color. Responses on the key when it is illuminated green are reinforced under a VI 30-s second schedule, but at anytime the organism may emit a response on the change-over key to change the first key color to red and change the contingencies associated with that key to the VI 60-s schedule. Using this preparation, Findley (1958) investigated switching between two options, and schedules interacting. These included examining various combinations of schedules and various contingencies for switching. For example, when using a progressive-ratio (PR) schedule on the change-over key, Findley found that switching occurred less frequently as the cost for switching became higher. Thus, similar to using a COD, separating responses by using larger work requirements can be effective in isolating contingencies.

In summary, early research using a concurrent preparation revealed factors contributing to performance on different simultaneously available schedules. If the schedules are separated temporally (COD), spatially, or by using a switching procedure, the contingencies associated with their respective response option are less likely to interact with the other contingency.

Concurrent VI Schedules and Matching

By far the most common concurrent preparation has been conc VI VI schedules. For example, in a VI 30-s schedule, the intervals between reinforcers vary, but average 30 s. There are several advantages of using VI schedules in a concurrent preparation as opposed to other basic schedules. First, interval schedules are preferable to ratio schedules (both fixed and variable ratios), because response allocation under concurrent ratio schedules typically settles
into an exclusive or almost exclusive preference for the smaller ratio (Herrnstein & Loveland, 1975). If a conc FR 5 FR20 were in effect the organism would quickly allocate its behavior to the richer of the two schedules (in this case a FR 5) and rarely (if ever) respond on the option that has a larger work requirement. Additionally, a VI schedule is advantageous to a FI schedule due to the unpredictability of reinforcement. The unpredictable availability of reinforcement under the VI schedule helps to produce a relatively consistent rate of responding.

Using several different concurrent VI schedules, Herrnstein (1961) discovered a phenomenon that would become a cornerstone of behavior analysis. In this procedure, pigeons were exposed to various conc VI VI schedules. For example, one condition arranged conc VI 2.25-min VI 4.5-min schedules. When this contingency was in effect, the experimental subject received approximately 27 reinforcers per hour on the first option and 13 reinforcers per hour on the second option. After running these contingencies for several sessions, the contingencies were changed to a different pair of VI schedules. As different reinforcer rates were implemented, behavior toward the two alternatives adjusted to the contingencies and began to show “matching.” That is, the proportion of behavior allocated to a given key was equal to (matched) the proportion of reinforcement obtained via responding on that key. This phenomenon would lead to what became known as the matching law. This relation is described by the simple equation:

\[
\frac{B_1}{B_1 + B_2} = \frac{R_1}{R_1 + R_2},
\]

where B refers to responses (behavior) and R refers to obtained reinforcers. The subscripts (1 and 2) refer to the two available options.

The matching law has proven to be an extremely valuable tool for behavior analysts; it describes behavioral allocation under conc VI VI schedules in a variety of species ranging from
pigeons (e.g., Herrnstein, 1961; Baum, 1974; 1979; 1981), humans (e.g., Conger & Killieen, 1974, Carr & McDowell, 1980; Borreto & Vollmer, 2002; Romanowich, Bourret & Vollmer, 2007), rats (e.g., Aparicio & Baum 2006; Graft, Lea & Whitworth, 1977), cows (e.g., Matthews & Temple, 1979; Foster, Temple, Robertson, Nair, & Poling, 1996), bees (e.g., Thuijsman, Peleg, Amitai & Shmida, 1995), crows (Richardson & Verbeek, 1987), and non-human primates (e.g., Anderson, Velkey & Woolverton, 2002, Corrado, Sugrue, Seung, & Newsome, 2005). Matching also has been demonstrated across several types of behaviors, including lever pressing, key pecking, chain pulling, standing, talking, and several others. Further, matching has been demonstrated across various types of reinforcers ranging from food and water, to intracranial brain stimulation, and social reinforcers (see McDowell, 1988 for review).

Although in many experiments, responding generally approximates the matching relation (e.g., deVillers, 1977; Davison & McCarthy, 1988); Baum (1974) noted that there were often systematic deviations from matching. Baum described three different types of deviation from strict matching. The most common type of deviation occurs when the distribution of responses on the two options is less extreme than would be predicted by matching. This deviation is called undermatching. A second deviation from matching occurs when the distribution of responses on the two options is more extreme than would be predicted by matching. This is called overmatching. The third type of deviation occurs when proportionately more behavior is allocated to a particular response option, regardless of relative reinforcement rate. This deviation is called bias.

Baum (1974) suggested that three factors could explain undermatching under concurrent VI schedules. The first is poor discrimination between alternatives. If the stimuli associated with the different contingencies are similar, it may be difficult for the stimuli to exert differential
control. The second is the degree the contingencies on one option affect responding on the other (see above discussion of compatible and incompatible concurrent operants). For example, in the absence of a COD, subjects often alternate frequently between the two options, resulting in undermatching. The final source of undermatching, according to Baum (1974), is deprivation. This third source of undermatching stems from findings reported by Herrnstein and Loveland (1974). Using a multiple-schedule preparation, their general findings were that as deprivation is decreased, overall responding decreases, but relative responding on both alternatives moves closer to matching.

The term overmatching is used to describe cases when relative responding on the two alternatives is more extreme than the matching law would predict. If a long COD is in effect (or some other method of making it difficult to change from one schedule to another, such as a large changeover ratio, Pliskoff & Fetterman, 1981), overmatching is likely to occur. The third deviation from matching described by Baum (1974) is bias. Bias refers to a systematic, proportional, preference for one option regardless of relative reinforcement frequency. Bias generally is considered to be the result of uncontrolled variables. For example, if two keylights are transilluminated yellow, but one of the bulbs happens to be brighter than the other, and this leads to a constant proportional preference for the option associated with the brighter key, then a bias for this alternative would be found. Overmatching and undermatching are on a continuum and therefore can be combined into one parameter, called sensitivity. Expressing the matching relation as response ratios (rather than as proportions), and adding these parameters, Baum (1974) proposed the following equation:

\[
\frac{B_1}{B_2} = c \left( \frac{R_1}{R_2} \right)^a,
\]
where $c$ refers to bias and $a$ refers to sensitivity. Baum further suggested a logarithmic transformation of this equation:

$$\log \left( \frac{B_1}{B_2} \right) = a \log \left( \frac{R_1}{R_2} \right) + \log c. \quad (3)$$

The advantage to performing the logarithmic transform is that the equation describes a linear function with sensitivity and bias indicated by the slope and y-intercept, respectively, thus making deviations more easily detectable by visual analysis.

Figure 1 illustrates the different deviations from matching discussed above. Line “A” illustrates “perfect” matching ($a = 1.0, \log c = 0$) where the ratio of responses equals the ratio of reinforcers. Line “B” represents underrating ($a < 1.0$); note that the slope of the line is shallower than that of line “A,” indicating a response ratio that is closer to indifference (i.e., equal responding on both keys) than would be predicted by matching. Line “C” represents overmatching ($a > 1.0$). The slope is steeper than predicted by matching (line “A”), indicating responses are allocated more towards the richer option (i.e., the one providing a higher reinforcement rate), and less toward the leaner option, than predicted by matching. Lines “D” and “E” represent bias with “D” representing a bias towards response option 1 and “E” representing a bias for response option 2.
Fig. 1. Hypothetical subject data. Plotted are the log response ratios on each two alternatives (subscript 1 and 2) as a function of their respective log reinforcer ratios. Line A represents matching, lines B and C represent undermatching and overmatching respectively and lines D and E represent bias for the first alternative and second alternative respectively.
Choice in Transition

Most of the research reviewed above utilized steady-state procedures. In this type of research, responding typically is allowed to occur until it is stable over a given number of sessions. This phase is referred to as a baseline. After a stable baseline has been established, experimental manipulations can begin. Conditions are held constant across several sessions, and data collected under stable conditions are aggregated (e.g., averaged) across sessions. After experimental data have been collected, they can be compared to the baseline data and the effects of the manipulation can be evaluated. This type of research is advantageous over between-subject designs, because the experimental data are compared with the baseline data (i.e. “control” data). Hence, the subject serves as its own control, eliminating intersubject variability as a potential source of confounding. With concurrent-schedule research, common manipulations made within the type of design are manipulations of reinforcement rate, reinforcement amount, and/or delay to reinforcement (for a more in depth discussion of steady-state procedures, refer to Perone, 1991; Sidman, 1961).

Steady-state procedures have been extremely successful in generating orderly relations between environmental and behavioral events. There has been recent interest however, in the study of “behavioral dynamics” (Marr, 1992). For example, what happens when the environment is variable (i.e., changes rapidly)? Several recent studies have addressed behavioral allocation under choice procedures that involve rapidly changing contingencies. For example, Hunter and Davison (1985) used a pseudorandom binary sequence (PRBS) to study choice in a variable environment. In this procedure, the particular options associated with two different reinforcer rates varied across sessions according to a 31-step PRBS. The schedules in effect during this experiment were VI 240 s and VI 60 s. On any given day, the richer schedule (VI
60 s) could be associated with responding on one key and the leaner schedule (VI 240 s) was associated with responding on the other key; the particular key associated with each schedule remained constant within a session, but varied unpredictably across sessions according to the PRBS. After a 31-session sequence was completed, it began again. After once through the 31-step PRBS, the pigeons’ responding came under control of the changing conditions. Sensitivity of behavior allocation in a given session to the reinforcer ratio in effect for that session was calculated using the generalized matching equation mentioned above (equation 3). Sensitivity to reinforcement rate ranged from 0.33-0.71 across birds during the second PRBS cycle; these values indicate undermatching. This degree of undermatching is comparable to that obtained in some studies using steady-state procedures (see Davison & McCarthy, 1988).

Schofield and Davison (1997) also used a PRBS procedure to study effects of reinforcer rate, this time using reinforcer rates that were more similar to each other than those used by Hunter and Davison (1985). Schofield and Davison used a reinforcer ratio of 1:2 or 2:1 and manipulated it via a PRBS. As in the Hunter and Davison (1985) experiment, responding became sensitive to the reinforcer contingencies for the current session with sensitivity ranging from 0.62-1.01. Again it should be noted that the range of sensitivities to reinforcement rate using this procedure was comparable to that previously reported for steady-state procedures (see Davison & McCarthy, 1988).

Grace, Bragason, and McLean (2003) used the PRBS procedure to investigate the effects of reinforcer delay. Pigeons were exposed to a concurrent-chains schedule. In the initial link, VI 10-s schedules were programmed for both keys. In the terminal link, an FI 8-s schedule was always in effect for responses on the left key (the standard key). The other terminal-link schedule was either an FI 4 s or an FI 16 s (the variable key). The contingencies associated with
the variable option changed according to a 31-step PRBS. Thus, on a given day, the terminal-link schedule for the variable key was either FI 4 s or FI 16 s. When the FI 4 s schedule was associated with the variable key, the delay to reinforcement was shorter for pecks on the variable key and when the FI 16-s schedule was associated with the variable key, the delay to reinforcement was shorter for pecks on the standard key. Thus, the ratio of reinforcement delays was either 1:2 or 2:1. Within this manipulation, responding within each session came under control of the delay to reinforcement; that is, responding occurred more frequently on the response option that delivered reinforcement with the shorter delay for that day. Their findings suggest that organisms can adapt rapidly to an environment that is quickly changing as shown by sensitivity that adjusted to the quickly changing environments.

Within a rapidly changing environment, sensitivity to reinforcement changes over the course of a session. When the richer alternative is not easily predictable (i.e., when the previous session’s contingencies are not predictive of the current session’s contingencies), response allocation tends to be approximately equal across both alternatives. After several reinforcers are delivered, response allocation begins to adjust. After sufficient exposure to the changing contingencies, responding towards the end of each session approaches matching (e.g., Hunter & Davison, 1985; Schofield & Davison, 1997; Grace et al., 2003).

When examining behavior in transition, an important measure is control by the contingencies currently in effect versus control of contingencies previously in effect. To calculate the control by current session’s contingencies, multiple-regression analyses have been utilized. In these analyses, response ratios from a given session are regressed against the reinforcer ratios in effect in that session, then against those in effect in the immediately preceding session, against those in effect in the session previous to that one, and so on. After
several exposures to the rapidly changing environment, behavior quickly comes under the control of current contingencies and not the contingencies from previous sessions. Calculating the sensitivity to the current reinforcement contingencies in effect has demonstrated that after a few reinforcers have been delivered, control by the current session’s contingencies take precedent over control by the contingencies arranged in previous sessions. Sensitivity to the previous session’s reinforcement rate (or delay), is either zero or near zero after the first few reinforcers had been obtained. Utilizing a variable environment procedure, carryover effects can be eliminated or at the least minimized.

Recently, investigators have employed choice procedures where contingencies change unpredictably within, rather than across, experimental sessions. Utilizing a procedure similar to one initially described by Belke and Heyman (1994), in a series of experiments, Davison, Baum, and colleagues varied reinforcer contingencies for two alternatives several times within sessions (Davison & Baum, 2000; 2002; 2003; 2004; 2006; 2007; Krägaloh & Davison, 2003; Krägaloh, Davison & Elliffe, 2005; Landon, Davison & Elliffe, 2003). The first study in this series was conducted by Davison and Baum (2000). The basic procedure described in this study was used subsequently throughout this series of experiments. Seven components with different reinforcer-rate ratios were arranged within each session. The reinforcer ratios were 27:1, 9:1, 3:1, 1:1, 1:3, 1:9, and 1:27 (Left: Right). A two-second COD was in effect throughout the experiment. Each session consisted of a presentation of each ratio (component) in a random order (each ratio was used once per session). Keylights were illuminated yellow in each component, and contingencies were not signaled in any of the components. Technically, the contingencies involved a seven-component mixed schedule with different concurrent schedules in each component. Components were separated by 10-s blackouts. In the initial study, several
manipulations were made to the basic procedure. These manipulations included overall rate of reinforcement (either 2.22 reinforcers per minute or 6 reinforcers per minute) and the number of reinforcers per component (ranging from 4 to 12). Each of the conditions lasted for a total of 50 sessions with data analysis performed on the last 35 sessions of each condition. Davison and Baum reported that, essentially, none of these manipulations affected the basic findings.

One of the analyses used by Davison and Baum was to calculate log response ratios (left/right) for each subject and graph them as a function of successive reinforcers within each component. Of particular interest was that response ratios changed on a reinforcer-by-reinforcer basis; that is, as more reinforcers were delivered, response ratios shifted toward the richer alternative. Further, in cases where the ratio was more disparate (i.e., the 27:1 versus 3:1), the ratio between responses on the two alternatives became more disparate. The change in response ratios as a function of successive reinforcers indicated that as more reinforcers were delivered, sensitivity of responding to reinforcer ratio increased. Within a component, sensitivity to reinforcer ratios peaked at approximately 0.5 (but when 12 reinforcers per component were arranged, sensitivity approached 0.65).

Davison and Baum (2000) developed a tentative model to describe the basic features of performance under their procedure. This model assumes that each reinforcer adds to an “accumulator” for its associated response. During times when no reinforcement is available (i.e., during a blackout period or during extinction), two processes occur. One is the gradual loss from both accumulators during the periods of non-reinforcement and the other is a gradual “confusion” (i.e., redistribution) of reinforcers in the two accumulators. In other words, during times when reinforcement is not being delivered, the effects of the previous reinforcers lose their effect, causing choice between the two choices to approach indifference.
Although sensitivity to reinforcement changed rapidly within a component, responses between the beginning of the component and the first reinforcer tended to be controlled by the previous reinforcer component in effect. After the first reinforcer was obtained, sensitivity to the reinforcement ratio in the previous component dropped drastically and the current reinforcer ratio began to control behavior. Thus, in a given component, a carryover effect was seen until the first reinforcer was delivered.

In addition to the analysis described above, Davison, Baum and colleagues (Davison & Baum, 2000; 2002; 2003; 2004; 2006; 2007; Krägaloh & Davison, 2003; Krägaloh, Davison & Elliffe, 2005; Landon, Davison & Elliffe, 2003) used other data analyses to examine responding in this preparation. One analysis involved examining effects of “confirmations” and “disconfirmations.” A confirmation occurs when two or more reinforcers occur consecutively via one alternative, and a disconfirmation occurs when a reinforcer is obtained via one option after one or more reinforcers had been obtained via the other option. In this analysis, sensitivity to reinforcement typically increased with increasing confirmations. When a disconfirmation occurred, the response ratios shifted immediately to near-zero, or to more responses being allocated to the other option.

Some of their subsequent studies were designed to investigate effects of some procedural variations on the basic findings reported by Davison and Baum (2000). For example, Davison and Baum (2002) manipulated blackout time between components to examine if carryover from the previous component was a function of time within the blackout. They found that carryover was minimized if a blackout of 10-s or more was used within the manipulation. In addition, Krägeloh and Davison (2003) manipulated the COD and investigated effects of providing signals indicating the reinforcer ratios in effect (i.e., arranging a multiple schedule). Removing the COD
resulted in a reduction to sensitivity of reinforcer rate, whereas adding signals increased sensitivity to reinforcement throughout the component (even before the first reinforcer was delivered).

Using the same general procedure described above, Davison and Baum (2002) provided additional analyses that would later provide much of the basis of their reformulation of the principle of reinforcement (see below). This analysis revealed what are called “preference pulses.” By calculating a response ratio of the “P” option (the response alternative that had just resulted in reinforcement, or the just productive alternative) to “N” options (the just not-productive alternative), Davison and Baum found that after a reinforcer was obtained, responses were emitted on that option in very high numbers, sometimes even reaching ratios of 1000:1. This effect occurred even when the reinforcer was delivered via the option providing a lower overall rate of food presentation. It should be noted that in these ratios, thousands of individual responses are aggregated into a single data point. These analyses begin by creating a ratio of P/N responses for the first response following a food presentation; the second data point represented response ratios for the second response, and so on. As more responses occur after a reinforcer, the ratio of P/N responses decreased and reached an asymptote at about log 0.5.

Davison and Baum (2002) suggest that preference pulses are ubiquitous when using within session manipulations of reinforcement. In addition to reinforcement rate, similar preference pulses have been revealed for manipulations of reinforcement amount (Davison & Baum 2003; Landon, Davison, & Elliffe 2003) and reinforcer delay (Davison & Baum, 2007) Davison, Baum and their colleagues have used the data provided in this series of studies to suggest that the entire notion of “reinforcement” needs to be reformulated. They suggest that food delivery is not acting to “strengthen” behavior upon which it is contingent. Rather, they
suggest that food presentation is a “phylogenetically important event” (PIE), and that food presentations essentially signal more food (more PIEs). In other words, according to these researchers, PIEs do not strengthen responses that produce (or precede) them, they act as signals for the potential of more PIEs coming from that option again. Conversely, they suggest that an aversive PIE does not punish behavior (i.e., weaken responding upon which it is contingent) but, rather, serves as a stimulus that more of the aversive stimulus will follow responding on that option; ergo, it is advantageous for the organism to change response allocation to another option (Davison & Baum, 2006)

To examine their notion of PIEs, Davison and Baum (2006) used the same rapidly changing environment procedure to investigate conditional “reinforcement.” As in their previous studies, seven unsignaled reinforcer-ratio components were arranged, with 10 food presentations per component. In this study, however, they arranged a set of conditions in which magazine-light-only presentations were interspersed among the food presentations (that also involved magazine-light presentation). In Experiment 1, magazine light only presentations were interspersed such that the magazine-light-only ratio (L:R) was perfectly correlated (r = +1) with the ratio of food-plus-magazine-light presentation. In Experiment 2, the correlation between magazine light only and food plus magazine light was manipulated. In one condition, there was a perfect negative correlation (r = -1) between magazine light only presentations and magazine light plus food presentations. For example, if the magazine light plus food ratio was 9:1 then the magazine light only ratio was 1:9. The findings for the condition revealed a magazine light plus food presentations produced positive preference pulses, whereas the magazine light only presentations produced “negative” preference pulses. That is, when a response produced a magazine light only presentation, immediately afterward responding occurred predominantly on
the other option. Finally, a previously neutral stimulus was added (a brief color change of the keylight). Two conditions examined brief changes in stimulus lights, in one condition keylight color changes were positively correlated with food presentation and in the other it was negatively correlated. These two conditions produced similar results as the magazine light only presentation, that is, when the stimulus light change ratio was positively correlated with food ratios, the stimulus alone produced a positive preference pulse. When the stimulus was negatively correlated, the stimulus produced a negative preference pulse. According to Davison and Baum (2006), the preference pulses obtained in these data provide more evidence for the PIE theory because what were normally considered conditional reinforcers seemed to instead be functioning as stimuli that signaled availability of food. For example, in the condition where the keylight changing color had a correlation of $r = +1$ with food presentation, it would typically be assumed that the presentation of the keylight change is functioning as a conditional reinforcer, what appeared to be occurring though is that the presentation of the keylight change appeared to signal food was available by continued responding on that option.

**Purpose of Present Study**

The purpose of this study was to directly replicate condition one of the Davison and Baum (2000) study. These researchers have made several claims stemming from their data about the nature of reinforcement (indeed, they have suggested that reinforcers do not reinforce at all). As such, their PIEs fly in the face of a long held, and arguably the most important, notion within behavior analysis. Their claims that PIEs should supplant traditional notions of reinforcement and punishment need to be examined further. It is important to note that, at this point, there have been relatively few replications of their results from other laboratories (but see Aparicio & Baum, 2006; Aparicio, 2007), and there have been failures to replicate some of their data
Thus, one issue addressed by the current study was the extent to which data presented by Davison, Baum, and colleagues are replicable.

Also, the data presented in the series of studies by Davison, Baum, and colleagues (Davison & Baum, 2000; 2002; 2003; 2004; 2006; 2007; Krägaloh & Davison, 2003; Krägaloh, Davison & Elliffe, 2005; Landon, Davison & Elliffe, 2003) were aggregated across numerous sessions consisting of thousands of responses per data point. Thus, another issue addressed by the current study was the degree these aggregated data were representative of those at other levels of aggregation. Another goal of this study was to examine response allocation at more local levels to determine if the overall data presented in this series of studies was in fact representative of what was actually happening on a component-by-component, reinforcer-by-reinforcer, and/or response-by-response basis. A final goal of this study was to characterize the development of behavioral allocation under these conditions. Davison and Baum’s data typically are aggregated over the final 35 of 50 sessions. One question concerns how rapidly the performance develops, and how stable it became across time.

METHOD

Subjects

Four experimentally naïve racing pigeons (*Columba livia*) from Double-T Farms (Glenwood, Iowa) were used as subjects. The birds were maintained at 85% of their free-feeding weight via post-session feeding of pigeon feed (Purina Pigeon Chow Checkers). Each pigeon was housed individually in a colony room with free access to health grit and water. The pigeon colony room was on a 12:12 hour light:dark cycle (lights turned on at 7:00 a.m.).
Apparatus

Four operant-conditioning chambers (BRS/LVE, Inc. model SEC-002) were used. Each chamber’s internal space was 35.0 cm deep by 30.5 cm wide by 36.0 cm high. The wall of each chamber to the right of the entry door was constructed of aluminum and contained three, 2.5-cm (diameter) response keys arranged horizontally, 26 cm above the chamber floor and 8.5 cm apart (center to center). Only the two side keys, each located 9.0 cm from its nearest side wall, were used; each key could be transilluminated yellow, red or green, and required approximately 0.25 N of force to activate its corresponding switch. A 5.0 cm by 6.0 cm rectangular opening was located 11.0 cm directly below the center key. This opening provided access to a food hopper containing milo grain; when the food hopper was raised, the opening was illuminated and all other lights in the chamber were extinguished. A 1.2-W houselight was located 6.5 cm directly above the center key. Green and red houselights, which were not used, were located 5 cm to the left and right of the white houselight, respectively. Each chamber was equipped with an exhaust fan for ventilation, and white noise was present in the room during sessions to mask extraneous sounds. Experimental events were programmed and data recorded by a Windows-based computer using Med Associates 4.0® (Georgia, VT) software and interface equipment located in an adjacent room; programming and recording occurred at a 0.01-s resolution.

Procedure

Upon arrival each pigeon was allowed free access to Pigeon Checkers to establish their free-feeding weight. After free-feed weight was established, a direct replication of Baum and Davison (2000) commenced. This began with the weights of the birds being reduced to 85% of their free-feeding weights. When a pigeon’s weight stabilized at this criterion for one week (cf. Kangas & Branch 2006), magazine training began. After a bird was eating consistently from the
hopper after presentation, an autoshaping procedure designed to train pecking on the two outer keys was initiated. In this autoshaping procedure, the house light was illuminated and the center key was transilluminated yellow, when the key was pecked, the houselight and keylight were extinguished, and the hopper light turned on and a 3.5-s hopper presentation occurred. If no response was made during a given interval of time (time intervals were 5, 10, 15, 20 and 25 s and were randomized) the houselight and keylight were extinguished, the hopper light turned on and a 3.5-s hopper presentation occurred. Each trial was separated by an 8-s intertrial interval. One of the birds (8418) did not peck during the autoshaping procedure, so keypecking was shaped manually by differentially reinforcing successive approximations. During the training and throughout the experiment whenever available, the left and right keylights were transilluminated with a yellow light.

Once keypecking was established, a series of reinforcement schedules, starting with continuous reinforcement and continuing to a VI 30-s were programmed. When keypecking on each key occurred reliably under the VI 30-s schedule, concurrent scheduling was arranged. In these sessions both the left and right keylights were illuminated yellow, the houselight was illuminated, and a dependent conc VI 30-s schedule was arranged. Within this dependent conc VI schedule arrangement, a single timer determined when reinforcement was arranged. When the appropriate length of time had elapsed, a probability gate was sampled and the reinforcer was arranged for a peck to one of the two keys according to predetermined probabilities. The probability of reinforcement was .5 for each key during this time. When responding occurred reliably on both keys, the within-session manipulation began.

The within-session procedure was nearly identical to the one used by Davison and Baum (2000). Sessions were divided into seven different components. During each component, food
delivery was programmed via a dependent conc VI 27-s schedule (i.e., food is available 2.22 times per min). Interval values were determined using a Flesher and Hoffman (1962) exponential progression with 10 values. Components utilized reinforcer-rate ratios (L:R) of 27:1, 9:1, 3:1, 1:1, 1:3, 1:9, and 1:27. For example, in the 9:1 component, after a reinforcer has been scheduled to be delivered, a probability gate was sampled, and reinforcement was 9 times more likely to be delivered by the left alternative as opposed to the right alternative. Each component occurred once per session, and the order was selected randomly without replacement. Each component was unsignaled, that is both the left and right keylights were both transilluminated yellow and the houselight was illuminated in each component. Each component remained in effect until 10 reinforcers were obtained (all interval values have been used). During reinforcement delivery, keylights and the houselight were extinguished, and a hopper light was illuminated. Components were separated by 10-s blackouts, during which keypecks were measured, but had no programmed consequences. After the 10-s blackout, a new reinforcer ratio was randomly selected from the remaining ratios. Sessions lasted until all seven components were completed. The direct replication of Davison and Baum (2000) involved 50 sessions with these contingencies in effect. To further characterize performance, an additional 50 sessions were conducted under these contingencies. Sessions were conducted 7 days a week.

Data Analysis

Within each session, pecks on the left and right keys and reinforcer deliveries via each option were time-stamped (at a 0.01-s resolution). From these raw numbers, data were analyzed over several levels of aggregation. The first level of analysis involved calculating response ratios on a reinforcer-by-reinforcer basis. This was done by obtaining response ratios from the beginning of each component until the first reinforcer was delivered, then from the first response
after the first reinforcer until the second reinforcer was delivered, and so forth until the component was completed. Using these aggregate data, sensitivity parameters were calculated (via equation 3) on a reinforcer-by-reinforcer basis.

The second level of analysis involved obtaining response ratios on a response-by-response basis. With this analysis, response ratios for the first response after reinforcer presentation were aggregated across sessions for each component. Following this, the response ratio for the second response following reinforcer presentation was analyzed for each component. This process continued for the first 40 responses after reinforcement. These data provided an analysis of the “preference pulses” reported by Davison and Baum (2003). Preference pulses were calculated by creating a ratio of “P” responses (responses to the option that has just delivered a reinforcer, or the just-productive option) and “N” responses (the response option that did not just deliver the reinforcer, the not just-productive option). Data from all components were collapsed to provide a preference pulses for their respective aggregate.

Analyses of the effects of sequences of reinforcer presentations also were conducted. Specifically, effects of “confirmations” (consecutive reinforcement on the same option) and “disconfirmations” (reinforcement delivered on one alternative after the other alternative delivered reinforcement) were examined in a manner similar to that reported by Davison and Baum (2003, 2004, 2006, 2007). Confirmations and disconfirmations were collapsed across components.

When using within-session manipulations, there can be a carryover of effects from the previous component into the component currently in effect. To examine potential carryover effects, a multiple-regression analysis was conducted. This analysis of carryover involved regressing the log response ratio in a given component against the log reinforcer ratio within that
component, and against the log reinforcer ratio of each of the three previous components. An examination of log response ratios for the entire component was conducted. In previous research it has been noted that sensitivity to the previous component is larger earlier in the component and dissipates as more reinforcers are earned in a component.

Davison, Baum, and colleagues typically present data aggregated across several sessions (usually the last 35 sessions of each condition). In the present study, the acquisition of within-component control, and reinforcer-by-reinforcer control, was analyzed across smaller blocks of sessions. Thus, the above analyses were conducted separately for sessions 1-10, 11-20, 21-30, 31-40, and 41-50. Of particular interest was the development of control by the current conditions in effect, the development of control by individual reinforcer deliveries, and the dissipation of carryover effects from component to component. Data from an additional 50 sessions were also analyzed in a similar fashion to examine the stability of these characteristics of performance across time.

RESULTS

Figures 2-5 show individual-subject, log-response ratios graphed as a function of obtained log-reinforcer ratios. Data for these graphs were calculated by aggregating responses and reinforcers from sessions 15-50 (as per Davison and Baum, 2000). Each panel represents response ratios between successive reinforcers within components. Panels marked 1 represent data from the beginning of a component until the first reinforcer was delivered, panels marked 2 represent data after the first reinforcer delivery but before the second one, and so on. After data were plotted in this manner, a linear regression was performed using equation 3; the resulting slope (the estimate of sensitivity to reinforcer rate) is noted in the bottom right corner of each panel. Within each panel, the leftmost data point represents data obtained within the 1:27
component. Its position on the x-axis was determined by the obtained reinforcer ratio for the component, and its position on the y-axis was obtained via the ratio of responses emitted during that component. The second point represents data collected from the 1:9 component and its location on the Cartesian Plane was derived in a similar fashion. For each bird, sensitivity to reinforcer rate began close to zero and steadily increased as more and more reinforcers were delivered within a component. Sensitivity stabilized after approximately 6 reinforcers for two birds (280 and 49889) and continued to climb until the end of a component for the other two (8418 and 17560). The maximum value ranged from 0.29 (49889) to 0.54 (8418).
Fig. 2. Subject 280. Log response ratio (Left to Right) graphed as a function of Log reinforcer ratio (Left to Right). Individual panels denote different successive reinforcers within a component.
Fig. 3. Subject 8418. Log response ratio (Left to Right) graphed as a function of Log reinforcer ratio (Left to Right). Individual panels denote different successive reinforcers within a component.
Fig. 4. Subject 17560. Log response ratio (Left to Right) graphed as a function of Log reinforcer ratio (Left to Right). Individual panels denote different successive reinforcers within a component.
Fig. 5. Subject 49889. Log response ratio (Left to Right) graphed as a function of Log reinforcer ratio (Left to Right). Individual panels denote different successive reinforcers within a component.
Figure 6 shows an analysis of “preference pulses.” Log P/N (just-productive alternative/not-just-productive alternative) response ratios graphed as a function of successive responses following reinforcement, up to the 40th response. Shown are individual subject data from sessions 15-50 aggregated across components. Immediately after reinforcement, the probability of responding on the just-productive alternative (i.e. “P” responses) was substantially higher than responding on the not just-productive alternative (“N” responses). After the initial response or two, the probability of a P response decreased across successive responses, eventually reaching an asymptote at a value between log 0 and 0.5. For birds 280 and 49889, the asymptote was reached relatively quickly (i.e., by the 10th response); whereas for birds 8418 and 17560 asymptote was reached at approximately the 20th response.

These data illustrate a substantially heightened probability of P responding immediately after reinforcement which dissipated by the 10th-20th response. Afterwards, responding still favored the just-productive alternative, though only slightly. A likely variable controlling this response pattern is that more often than not, the just-productive alternative was the alternative that provided an overall higher probability of reinforcement. There was only one component (1:1 or equal probability of reinforcement from either alternative) out of seven components where the contingencies in effect did not favor continued responding on one alternative.
Fig. 6. Preference pulses for each subject. Log response ratios for just productive alternative (P) and not just productive alternatives (N) graphed as a function of responses following a reinforcer. Data were taken from sessions 15-50.
Figure 7 shows log response ratios (left to right) as a function of successive reinforcers. Data were collected from sessions 15-50 and aggregated across components. In this graph closed circles designate confirmations, or responses after a reinforcer obtained from same alternative consecutively and open circles designate disconfirmations, or responses after a reinforcer is obtained via one option after one or more reinforcers had been obtained via the other option. The first filled circle on each graph represents the log response ratio obtained from the beginning of a component until the first reinforcer is obtained. The second filled circle represents response ratios after the first reinforcer has been delivered, but before the second reinforcer in a component has been delivered, the curve shifting upwards indicates responses following a reinforcer on the left alternative and the curves shifting downward indicate responses following a reinforcer on the right alternative. Filled circles following these are further confirmations on their respective alternatives. The open circles denote disconfirmations. For example, conditions in which the first two reinforcers of a component were obtained via the left alternative followed by a reinforcer obtained by the right alternative are illustrated by two rising closed circles connected by a solid line above 1 and 2 on the x-axis followed by an open circle connected by a dashed line.

Similar to Davison and Baum’s data, as more reinforcers were obtained via one option, more and more responses were allocated to that alternative (i.e., as consecutive reinforcers were “accumulated” via responding on the left or right key, the more and more responses were allocated to that key). Interestingly, regardless of how many consecutive reinforcers had been obtained, a single disconfirmation, for the most part, “reset” responding. That is, after a disconfirmation had occurred, response ratios shifted back to values that were obtained before a reinforcer had been delivered in a component.
Figure 8 shows the results of the multiple-regression analysis. In this figure, sensitivity is plotted as a function of component lag for all 10 reinforcers. The purpose of this analysis was to estimate the degree to which responding in a given component was controlled by the reinforcer rate in effect during that component and by the reinforcer rate in effect during previous components. A lag of zero (e.g. the first data point on each graph) indicates sensitivity to the reinforcer rate currently in effect and was conducted by regressing the log response ratio obtained in a given component against the obtained log reinforcer ratio for that component. A lag of 1 (e.g. the second data point on each graph) indicates the obtained log response ratio of a given component regressed against the obtained log reinforcer rate of the previous component. A lag of 2 and 3 represent the log response ratio of a given component against the log reinforcer rate that was in effect 2 and 3 (respectively) components previously. For all four birds, sensitivity is highest at lag 0 indicating that responding was primarily controlled by the reinforcer ratio currently in effect. In addition, lag 1 values were greater than zero (particularly for birds 8418 and 49889), indicating some control by the reinforcer ratio in effect during the immediately preceding component. Sensitivity values at lags 2 and 3 typically were close to zero.
Fig. 7. Log response ratios (left to right) graphed as a function of reinforcers delivered during a component. Filled circles connected by solid lines indicate consecutive reinforcers obtained via the same option (“confirmations”), and open circles connected to the filled circles by dashed lines denote reinforcers delivered by an alternative after consecutive reinforcers had been delivered by the other option (“disconfirmations”).
Fig. 8. Sensitivity to reinforcement rate graphed as a function of lag. The first data point on each graph (lag 0) shows sensitivity of responding in the current component to the reinforcer ratio in effect during that component, the second data point (lag 1) shows sensitivity of responding in the current component to the reinforcer ratio in effect in the immediately preceding component, and so on.
The purpose of the above analyses was to determine if the results of Davison and Baum (2000) could be replicated outside of their laboratories. Overall, the present data, when aggregated over 35 sessions closely resembled their data. Sensitivity adjusted rapidly within each component (Figures 2-5) and preference pulses occurred favoring a higher probability of responding on the just productive alternative (Figure 6). Response “trees” illustrated that successive confirmations produced an increasing proportion of responses toward the just reinforced alternative, and a single disconfirmations drove the response ratio close the response ratio that was produced before any reinforcers occurred in a component (Figure 7). Finally, the response ratio in a given component was controlled primarily by the reinforcer ratio currently in effect; that is, carryover from previous components was minimal (Figure 8).

Because the aggregate data were similar to those of Davison, Baum and colleagues, the same analyses were conducted using smaller aggregates of data. The size of the aggregates used for the following analyses were blocks of 10 sessions. Data obtained in sessions 1-100 were used in the following analyses.

Plotted in Figures 9 and 10 are obtained sensitivity estimates aggregated in 10-session blocks for sessions 1-50 and 51-100 respectively. These data were analyzed by conducting linear-regression analysis of data in which log response ratios are plotted as a function of log obtained reinforcer ratios across successive reinforcers within a component (i.q. Figures 2-5). Instead of plotting data in the same fashion as Figures 2-5, for the sake of brevity, Figures 9 and 10 show sensitivity as a function of successive reinforcers. These estimates are derived from the slopes of the linear regressions and are similar to the \( a \) values denoted in Figures 2-5. As in the analysis of larger aggregates of sessions, sensitivity of responding to the reinforcer ratio started approximately at zero and increased as a function of reinforcer deliveries within a component.
There are several features that should be noted within the graphs shown in Figures 9 and 10. First, for two of the birds (8418 & 17560) there appeared to be a systematic increase in the terminal sensitivity value across blocks. For example, for bird 17560, in Figure 9 the last data point for the 41-50 block was higher (a=0.54) than for the 1-10 block (a=0.29) sensitivity estimates for the other blocks of sessions fall in between. Similarly, for bird 8418, sensitivity estimates for blocks 1-10 were lower (0.39) than for the 41-50 block (0.54). In contrast, for birds 280 and 49889 there was relatively little change in sensitivity across blocks of ten sessions.

When comparing Figures 9 and 10 (sessions 1-50 and 51-100), two things become apparent. One is that for all birds there was a slight increase in sensitivity in the second 50 sessions compared to the first. For the most part, the entire curve is shifted upwards for all the subjects across successive reinforcers. Second, for birds 8418 and 17560 in the last 50 sessions, sensitivity functions tended to fall on top of one another, indicating that response allocation across reinforcers within a component was more consistent across blocks in sessions 50-100 than in sessions 1-50.

A final important note regarding Figure 9 is related to response allocation within the first 10 sessions. The analyses for these sessions reveal that the response pattern is acquired very rapidly. All four of the birds’ sensitivity in the first 10 sessions is similar to those found in the other blocks and indeed found in much of the past data collected by Davison, Baum and colleagues. That is, sensitivity of responding to reinforcer rate started out at approximately zero and then grew with successive reinforcer deliveries. (Table 1 contains the sensitivity values graphed in Figures 9 and 10 as well as estimates of bias and coefficients of determination (R²) for each subject.)
Fig. 9. Sensitivity to reinforcer rate graphed as a function of reinforcers delivered in components for the first 50 sessions.
Fig. 10. Sensitivity to reinforcer rate graphed as a function of reinforcers delivered in components for sessions 51-100.
Table 1. Individual Subject Sensitivity Parameter (A), Bias and Coefficient of Determination ($R^2$) Values on a Reinforcer by Reinforcer Basis in Blocks of 10 Sessions

<table>
<thead>
<tr>
<th></th>
<th>280</th>
<th>8418</th>
<th>17560</th>
<th>49889</th>
</tr>
</thead>
<tbody>
<tr>
<td>S$^{R^+}$</td>
<td>A</td>
<td>Bias</td>
<td>$R^2$</td>
<td>A</td>
</tr>
<tr>
<td>Sess 1-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-0.055</td>
<td>0.329</td>
<td>0.061</td>
<td>-0.091</td>
</tr>
<tr>
<td>2</td>
<td>0.123</td>
<td>0.305</td>
<td>0.594</td>
<td>0.085</td>
</tr>
<tr>
<td>3</td>
<td>0.134</td>
<td>0.268</td>
<td>0.868</td>
<td>0.294</td>
</tr>
<tr>
<td>4</td>
<td>0.174</td>
<td>0.341</td>
<td>0.803</td>
<td>0.219</td>
</tr>
<tr>
<td>5</td>
<td>0.189</td>
<td>0.212</td>
<td>0.782</td>
<td>0.334</td>
</tr>
<tr>
<td>6</td>
<td>0.336</td>
<td>0.255</td>
<td>0.922</td>
<td>0.399</td>
</tr>
<tr>
<td>7</td>
<td>0.279</td>
<td>0.200</td>
<td>0.865</td>
<td>0.343</td>
</tr>
<tr>
<td>8</td>
<td>0.351</td>
<td>0.294</td>
<td>0.916</td>
<td>0.459</td>
</tr>
<tr>
<td>9</td>
<td>0.419</td>
<td>0.191</td>
<td>0.979</td>
<td>0.388</td>
</tr>
<tr>
<td>10</td>
<td>0.390</td>
<td>0.205</td>
<td>0.834</td>
<td>0.397</td>
</tr>
<tr>
<td>Sess 11-20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.073</td>
<td>0.163</td>
<td>0.194</td>
<td>-0.020</td>
</tr>
<tr>
<td>2</td>
<td>0.134</td>
<td>0.136</td>
<td>0.445</td>
<td>0.049</td>
</tr>
<tr>
<td>3</td>
<td>0.257</td>
<td>0.188</td>
<td>0.964</td>
<td>0.041</td>
</tr>
<tr>
<td>4</td>
<td>0.237</td>
<td>0.232</td>
<td>0.874</td>
<td>0.134</td>
</tr>
<tr>
<td>5</td>
<td>0.331</td>
<td>0.147</td>
<td>0.956</td>
<td>0.359</td>
</tr>
<tr>
<td>6</td>
<td>0.346</td>
<td>0.207</td>
<td>0.991</td>
<td>0.461</td>
</tr>
<tr>
<td>7</td>
<td>0.289</td>
<td>0.247</td>
<td>0.852</td>
<td>0.315</td>
</tr>
<tr>
<td>8</td>
<td>0.339</td>
<td>0.235</td>
<td>0.896</td>
<td>0.294</td>
</tr>
<tr>
<td>9</td>
<td>0.346</td>
<td>0.314</td>
<td>0.928</td>
<td>0.414</td>
</tr>
<tr>
<td>10</td>
<td>0.393</td>
<td>0.285</td>
<td>0.941</td>
<td>0.374</td>
</tr>
</tbody>
</table>
Table 1 Cont.

<table>
<thead>
<tr>
<th></th>
<th>280</th>
<th>8418</th>
<th>17560</th>
<th>49889</th>
</tr>
</thead>
<tbody>
<tr>
<td>S^{R+}</td>
<td>A</td>
<td>Bias</td>
<td>R^2</td>
<td>A</td>
</tr>
<tr>
<td>Sess 21-30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-0.052</td>
<td>0.234</td>
<td>0.292</td>
<td>-0.142</td>
</tr>
<tr>
<td>2</td>
<td>0.023</td>
<td>0.270</td>
<td>0.105</td>
<td>0.153</td>
</tr>
<tr>
<td>3</td>
<td>0.080</td>
<td>0.208</td>
<td>0.537</td>
<td>0.192</td>
</tr>
<tr>
<td>4</td>
<td>0.188</td>
<td>0.255</td>
<td>0.925</td>
<td>0.206</td>
</tr>
<tr>
<td>5</td>
<td>0.205</td>
<td>0.187</td>
<td>0.852</td>
<td>0.311</td>
</tr>
<tr>
<td>6</td>
<td>0.263</td>
<td>0.162</td>
<td>0.890</td>
<td>0.390</td>
</tr>
<tr>
<td>7</td>
<td>0.298</td>
<td>0.199</td>
<td>0.942</td>
<td>0.439</td>
</tr>
<tr>
<td>8</td>
<td>0.242</td>
<td>0.167</td>
<td>0.772</td>
<td>0.458</td>
</tr>
<tr>
<td>9</td>
<td>0.263</td>
<td>0.170</td>
<td>0.918</td>
<td>0.413</td>
</tr>
<tr>
<td>10</td>
<td>0.332</td>
<td>0.123</td>
<td>0.919</td>
<td>0.786</td>
</tr>
<tr>
<td>Sess 31-40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-0.054</td>
<td>0.236</td>
<td>0.147</td>
<td>-0.114</td>
</tr>
<tr>
<td>2</td>
<td>0.140</td>
<td>0.113</td>
<td>0.698</td>
<td>0.131</td>
</tr>
<tr>
<td>3</td>
<td>0.169</td>
<td>0.221</td>
<td>0.603</td>
<td>0.198</td>
</tr>
<tr>
<td>4</td>
<td>0.228</td>
<td>0.183</td>
<td>0.891</td>
<td>0.280</td>
</tr>
<tr>
<td>5</td>
<td>0.208</td>
<td>0.160</td>
<td>0.745</td>
<td>0.302</td>
</tr>
<tr>
<td>6</td>
<td>0.284</td>
<td>0.220</td>
<td>0.885</td>
<td>0.364</td>
</tr>
<tr>
<td>7</td>
<td>0.421</td>
<td>0.284</td>
<td>0.838</td>
<td>0.519</td>
</tr>
<tr>
<td>8</td>
<td>0.289</td>
<td>0.198</td>
<td>0.756</td>
<td>0.492</td>
</tr>
<tr>
<td>9</td>
<td>0.344</td>
<td>0.188</td>
<td>0.960</td>
<td>0.709</td>
</tr>
<tr>
<td>10</td>
<td>0.366</td>
<td>0.214</td>
<td>0.910</td>
<td>0.595</td>
</tr>
</tbody>
</table>
Table 1 cont.

<table>
<thead>
<tr>
<th></th>
<th>S\textsuperscript{R+}</th>
<th>A</th>
<th>Bias</th>
<th>R\textsuperscript{2}</th>
<th>A</th>
<th>Bias</th>
<th>R\textsuperscript{2}</th>
<th>A</th>
<th>Bias</th>
<th>R\textsuperscript{2}</th>
<th>A</th>
<th>Bias</th>
<th>R\textsuperscript{2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sess 41-50</td>
<td>1</td>
<td>-0.039</td>
<td>0.111</td>
<td>0.106</td>
<td>0.050</td>
<td>-0.047</td>
<td>0.116</td>
<td>-0.105</td>
<td>0.271</td>
<td>0.405</td>
<td>-0.075</td>
<td>-0.075</td>
<td>0.210</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.104</td>
<td>0.106</td>
<td>0.504</td>
<td>0.284</td>
<td>0.108</td>
<td>0.750</td>
<td>0.087</td>
<td>0.245</td>
<td>0.309</td>
<td>0.053</td>
<td>0.053</td>
<td>0.339</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.189</td>
<td>0.034</td>
<td>0.928</td>
<td>0.316</td>
<td>0.196</td>
<td>0.874</td>
<td>0.207</td>
<td>0.215</td>
<td>0.811</td>
<td>0.115</td>
<td>0.115</td>
<td>0.549</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.211</td>
<td>0.064</td>
<td>0.669</td>
<td>0.428</td>
<td>0.106</td>
<td>0.907</td>
<td>0.282</td>
<td>0.229</td>
<td>0.959</td>
<td>0.103</td>
<td>0.103</td>
<td>0.358</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.318</td>
<td>0.071</td>
<td>0.867</td>
<td>0.540</td>
<td>0.399</td>
<td>0.912</td>
<td>0.353</td>
<td>0.266</td>
<td>0.987</td>
<td>0.277</td>
<td>0.277</td>
<td>0.792</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.263</td>
<td>0.062</td>
<td>0.931</td>
<td>0.517</td>
<td>0.162</td>
<td>0.875</td>
<td>0.390</td>
<td>0.243</td>
<td>0.927</td>
<td>0.327</td>
<td>0.327</td>
<td>0.902</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.422</td>
<td>0.094</td>
<td>0.895</td>
<td>0.567</td>
<td>0.020</td>
<td>0.939</td>
<td>0.451</td>
<td>0.214</td>
<td>0.959</td>
<td>0.242</td>
<td>0.242</td>
<td>0.824</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.297</td>
<td>0.089</td>
<td>0.919</td>
<td>0.550</td>
<td>0.133</td>
<td>0.967</td>
<td>0.439</td>
<td>0.213</td>
<td>0.962</td>
<td>0.279</td>
<td>0.279</td>
<td>0.934</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.293</td>
<td>0.084</td>
<td>0.974</td>
<td>0.619</td>
<td>0.124</td>
<td>0.955</td>
<td>0.505</td>
<td>0.110</td>
<td>0.926</td>
<td>0.285</td>
<td>0.285</td>
<td>0.930</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.316</td>
<td>0.094</td>
<td>0.890</td>
<td>0.588</td>
<td>0.167</td>
<td>0.858</td>
<td>0.524</td>
<td>0.128</td>
<td>0.937</td>
<td>0.290</td>
<td>0.290</td>
<td>0.898</td>
</tr>
<tr>
<td>Sess 51-60</td>
<td>1</td>
<td>0.008</td>
<td>0.154</td>
<td>0.010</td>
<td>-0.050</td>
<td>0.120</td>
<td>0.014</td>
<td>-0.156</td>
<td>0.096</td>
<td>0.475</td>
<td>0.062</td>
<td>0.062</td>
<td>0.284</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.037</td>
<td>0.051</td>
<td>0.046</td>
<td>0.210</td>
<td>0.201</td>
<td>0.280</td>
<td>0.162</td>
<td>0.164</td>
<td>0.406</td>
<td>0.030</td>
<td>0.030</td>
<td>0.126</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.158</td>
<td>0.087</td>
<td>0.621</td>
<td>0.186</td>
<td>0.249</td>
<td>0.195</td>
<td>0.235</td>
<td>0.131</td>
<td>0.851</td>
<td>0.191</td>
<td>0.191</td>
<td>0.741</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.287</td>
<td>0.072</td>
<td>0.643</td>
<td>0.411</td>
<td>0.278</td>
<td>0.831</td>
<td>0.208</td>
<td>0.101</td>
<td>0.715</td>
<td>0.208</td>
<td>0.208</td>
<td>0.918</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.302</td>
<td>0.165</td>
<td>0.801</td>
<td>0.540</td>
<td>0.222</td>
<td>0.778</td>
<td>0.415</td>
<td>0.077</td>
<td>0.940</td>
<td>0.246</td>
<td>0.246</td>
<td>0.946</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.380</td>
<td>0.200</td>
<td>0.987</td>
<td>0.640</td>
<td>0.252</td>
<td>0.955</td>
<td>0.432</td>
<td>0.148</td>
<td>0.978</td>
<td>0.304</td>
<td>0.304</td>
<td>0.872</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.243</td>
<td>0.114</td>
<td>0.881</td>
<td>0.750</td>
<td>0.352</td>
<td>0.864</td>
<td>0.450</td>
<td>0.090</td>
<td>0.878</td>
<td>0.229</td>
<td>0.229</td>
<td>0.801</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>0.232</td>
<td>0.113</td>
<td>0.922</td>
<td>0.703</td>
<td>0.121</td>
<td>0.968</td>
<td>0.466</td>
<td>0.072</td>
<td>0.939</td>
<td>0.312</td>
<td>0.312</td>
<td>0.975</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.281</td>
<td>0.023</td>
<td>0.814</td>
<td>0.682</td>
<td>0.251</td>
<td>0.979</td>
<td>0.358</td>
<td>0.151</td>
<td>0.784</td>
<td>0.293</td>
<td>0.293</td>
<td>0.857</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.517</td>
<td>0.258</td>
<td>0.806</td>
<td>0.771</td>
<td>0.115</td>
<td>0.896</td>
<td>0.444</td>
<td>0.117</td>
<td>0.927</td>
<td>0.400</td>
<td>0.400</td>
<td>0.956</td>
</tr>
<tr>
<td></td>
<td>S_{R^+}</td>
<td>A</td>
<td>Bias</td>
<td>R^2</td>
<td>A</td>
<td>Bias</td>
<td>R^2</td>
<td>A</td>
<td>Bias</td>
<td>R^2</td>
<td>A</td>
<td>Bias</td>
<td>R^2</td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
<td>-------</td>
<td>------</td>
<td>------</td>
<td>-------</td>
<td>------</td>
<td>------</td>
<td>-------</td>
<td>------</td>
<td>------</td>
<td>-------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Sess 61-70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-0.064</td>
<td>0.104</td>
<td>0.251</td>
<td>-0.059</td>
<td>0.254</td>
<td>0.068</td>
<td>0.036</td>
<td>0.198</td>
<td>0.022</td>
<td>-0.024</td>
<td>-0.024</td>
<td>0.112</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.100</td>
<td>0.003</td>
<td>0.428</td>
<td>0.078</td>
<td>0.274</td>
<td>0.090</td>
<td>0.218</td>
<td>0.152</td>
<td>0.520</td>
<td>0.132</td>
<td>0.132</td>
<td>0.669</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.180</td>
<td>0.032</td>
<td>0.902</td>
<td>0.301</td>
<td>0.345</td>
<td>0.482</td>
<td>0.295</td>
<td>0.110</td>
<td>0.907</td>
<td>0.169</td>
<td>0.169</td>
<td>0.810</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.158</td>
<td>0.077</td>
<td>0.542</td>
<td>0.397</td>
<td>0.285</td>
<td>0.942</td>
<td>0.336</td>
<td>0.111</td>
<td>0.893</td>
<td>0.209</td>
<td>0.209</td>
<td>0.911</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.336</td>
<td>0.057</td>
<td>0.872</td>
<td>0.422</td>
<td>0.170</td>
<td>0.755</td>
<td>0.369</td>
<td>-0.007</td>
<td>0.894</td>
<td>0.247</td>
<td>0.247</td>
<td>0.933</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.403</td>
<td>0.100</td>
<td>0.934</td>
<td>0.652</td>
<td>0.418</td>
<td>0.872</td>
<td>0.359</td>
<td>-0.006</td>
<td>0.899</td>
<td>0.302</td>
<td>0.302</td>
<td>0.974</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.344</td>
<td>0.004</td>
<td>0.923</td>
<td>0.581</td>
<td>0.305</td>
<td>0.781</td>
<td>0.418</td>
<td>0.035</td>
<td>0.966</td>
<td>0.366</td>
<td>0.366</td>
<td>0.899</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.379</td>
<td>-0.020</td>
<td>0.957</td>
<td>0.701</td>
<td>0.363</td>
<td>0.919</td>
<td>0.357</td>
<td>0.018</td>
<td>0.965</td>
<td>0.417</td>
<td>0.417</td>
<td>0.830</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.334</td>
<td>0.079</td>
<td>0.914</td>
<td>0.677</td>
<td>0.164</td>
<td>0.958</td>
<td>0.517</td>
<td>0.009</td>
<td>0.927</td>
<td>0.367</td>
<td>0.367</td>
<td>0.852</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.364</td>
<td>0.044</td>
<td>0.945</td>
<td>0.686</td>
<td>0.266</td>
<td>0.992</td>
<td>0.494</td>
<td>0.081</td>
<td>0.905</td>
<td>0.343</td>
<td>0.343</td>
<td>0.957</td>
<td></td>
</tr>
<tr>
<td>Sess 71-80</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>-0.014</td>
<td>0.186</td>
<td>0.017</td>
<td>-0.115</td>
<td>0.107</td>
<td>0.318</td>
<td>-0.134</td>
<td>0.217</td>
<td>0.352</td>
<td>0.077</td>
<td>0.077</td>
<td>0.350</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.112</td>
<td>0.091</td>
<td>0.529</td>
<td>0.189</td>
<td>0.178</td>
<td>0.496</td>
<td>0.098</td>
<td>0.172</td>
<td>0.149</td>
<td>0.110</td>
<td>0.110</td>
<td>0.813</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.200</td>
<td>0.076</td>
<td>0.821</td>
<td>0.290</td>
<td>0.098</td>
<td>0.760</td>
<td>0.273</td>
<td>0.159</td>
<td>0.601</td>
<td>0.226</td>
<td>0.226</td>
<td>0.799</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.170</td>
<td>0.063</td>
<td>0.910</td>
<td>0.349</td>
<td>0.111</td>
<td>0.723</td>
<td>0.251</td>
<td>0.125</td>
<td>0.867</td>
<td>0.320</td>
<td>0.320</td>
<td>0.949</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.218</td>
<td>0.130</td>
<td>0.804</td>
<td>0.373</td>
<td>0.054</td>
<td>0.843</td>
<td>0.550</td>
<td>-0.049</td>
<td>0.840</td>
<td>0.336</td>
<td>0.336</td>
<td>0.974</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.365</td>
<td>0.136</td>
<td>0.881</td>
<td>0.605</td>
<td>0.166</td>
<td>0.882</td>
<td>0.442</td>
<td>0.064</td>
<td>0.972</td>
<td>0.448</td>
<td>0.448</td>
<td>0.960</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.315</td>
<td>0.138</td>
<td>0.948</td>
<td>0.497</td>
<td>0.198</td>
<td>0.869</td>
<td>0.451</td>
<td>0.027</td>
<td>0.911</td>
<td>0.406</td>
<td>0.406</td>
<td>0.803</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.313</td>
<td>0.069</td>
<td>0.906</td>
<td>0.587</td>
<td>0.087</td>
<td>0.928</td>
<td>0.543</td>
<td>0.070</td>
<td>0.965</td>
<td>0.485</td>
<td>0.485</td>
<td>0.831</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.379</td>
<td>0.133</td>
<td>0.905</td>
<td>0.566</td>
<td>0.264</td>
<td>0.907</td>
<td>0.497</td>
<td>0.110</td>
<td>0.951</td>
<td>0.367</td>
<td>0.367</td>
<td>0.935</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.571</td>
<td>0.132</td>
<td>0.942</td>
<td>0.534</td>
<td>0.146</td>
<td>0.909</td>
<td>0.538</td>
<td>0.172</td>
<td>0.890</td>
<td>0.506</td>
<td>0.506</td>
<td>0.854</td>
<td></td>
</tr>
</tbody>
</table>
Table 1 cont.

\[
\begin{array}{ccccccccccc}
S^{R+} & A & \text{Bias} & R^2 & A & \text{Bias} & R^2 & A & \text{Bias} & R^2 & A & \text{Bias} & R^2 \\
\hline
\text{Sess 81-90} & & & & & & & & & & & & \\
1 & -0.111 & 0.248 & 0.259 & -0.105 & 0.058 & 0.405 & -0.055 & 0.265 & 0.034 & -0.050 & -0.050 & 0.193 \\
2 & 0.113 & 0.178 & 0.750 & 0.150 & 0.162 & 0.527 & 0.163 & 0.068 & 0.517 & 0.123 & 0.123 & 0.645 \\
3 & 0.245 & 0.125 & 0.907 & 0.276 & 0.195 & 0.685 & 0.323 & 0.317 & 0.584 & 0.233 & 0.233 & 0.583 \\
4 & 0.318 & 0.157 & 0.901 & 0.469 & 0.167 & 0.784 & 0.306 & 0.157 & 0.770 & 0.268 & 0.268 & 0.697 \\
5 & 0.303 & 0.150 & 0.887 & 0.520 & 0.189 & 0.884 & 0.458 & 0.113 & 0.961 & 0.334 & 0.334 & 0.945 \\
6 & 0.330 & 0.121 & 0.842 & 0.628 & 0.362 & 0.828 & 0.405 & 0.160 & 0.795 & 0.363 & 0.363 & 0.848 \\
7 & 0.264 & 0.130 & 0.815 & 0.540 & 0.331 & 0.830 & 0.442 & 0.228 & 0.840 & 0.289 & 0.289 & 0.915 \\
8 & 0.334 & 0.223 & 0.884 & 0.545 & 0.216 & 0.949 & 0.471 & 0.155 & 0.846 & 0.314 & 0.314 & 0.936 \\
9 & 0.329 & 0.192 & 0.793 & 0.731 & 0.369 & 0.778 & 0.468 & 0.205 & 0.916 & 0.302 & 0.302 & 0.919 \\
10 & 0.341 & 0.234 & 0.845 & 0.602 & 0.199 & 0.964 & 0.500 & 0.246 & 0.857 & 0.356 & 0.356 & 0.884 \\
\text{Sess 91-100} & & & & & & & & & & & & \\
1 & -0.018 & 0.177 & 0.012 & -0.072 & 0.094 & 0.142 & 0.041 & 0.186 & 0.052 & -0.087 & -0.087 & 0.350 \\
2 & 0.161 & 0.154 & 0.521 & 0.192 & 0.175 & 0.506 & 0.276 & 0.171 & 0.750 & 0.078 & 0.078 & 0.238 \\
3 & 0.302 & 0.251 & 0.814 & 0.152 & 0.319 & 0.527 & 0.376 & 0.047 & 0.857 & 0.198 & 0.198 & 0.831 \\
4 & 0.345 & 0.237 & 0.877 & 0.391 & 0.252 & 0.857 & 0.334 & 0.122 & 0.861 & 0.190 & 0.190 & 0.898 \\
5 & 0.337 & 0.248 & 0.933 & 0.464 & 0.286 & 0.839 & 0.362 & 0.028 & 0.910 & 0.245 & 0.245 & 0.919 \\
6 & 0.340 & 0.108 & 0.822 & 0.537 & 0.288 & 0.929 & 0.476 & 0.133 & 0.937 & 0.198 & 0.198 & 0.876 \\
7 & 0.394 & 0.134 & 0.856 & 0.534 & 0.184 & 0.892 & 0.510 & 0.056 & 0.885 & 0.299 & 0.299 & 0.934 \\
8 & 0.561 & 0.309 & 0.797 & 0.606 & 0.367 & 0.905 & 0.476 & 0.029 & 0.915 & 0.327 & 0.327 & 0.779 \\
9 & 0.347 & 0.191 & 0.853 & 0.664 & 0.192 & 0.959 & 0.506 & 0.065 & 0.961 & 0.288 & 0.288 & 0.815 \\
10 & 0.343 & 0.172 & 0.854 & 0.615 & 0.325 & 0.936 & 0.607 & 0.088 & 0.980 & 0.254 & 0.254 & 0.898 \\
\end{array}
\]
Figures 11 and 12 present the results of a preference-pulse analysis across 10-session blocks. This analysis is similar to the one presented in Figure 6, but due to the smaller number of responses, proportions, rather than ratios, were used. Again, similar to the analysis of the larger aggregate, responding after a reinforcer was almost exclusively allocated toward the just productive alternative (P), as designated by the pulse starting at one, and then rapidly shifting closer to equal responding (i.e. a proportion of 0.5). It should be noted that for the three of the subjects, this pattern developed early (within the first 10 sessions). For the remaining subject (8418), the effect developed more slowly and was not pronounced until the 31-40 session block. After this block, responding stabilized and was similar for the remainder of the sessions. Similar to the data presented in Figures 9 and 10, these data illustrate how quickly this response pattern developed. For three of the four birds this pattern developed within 10 sessions and continued through the course of the experiment. That is, the first response following a reinforcer typically was allocated to the P alternative, and as successive responses occur responding shifted toward equal responding on both alternatives. Although this general pattern emerged rather quickly, it tended to become more pronounced over the course of several sessions. This was particularly evident when comparing data from sessions 1-50 with those from sessions 51-100. In these latter sessions, the data points overlap considerably for each block of 10 sessions.
Fig. 11. Individual subject data, proportion of just productive alternatives to the total amount of responses graphed as a function of responses after reinforcement for the first 50 sessions.
Fig. 12. Individual subject data, proportion of just productive alternatives to the total amount of responses graphed as a function of responses after reinforcement for sessions 51-100.
Plotted in Figures 13-20 are response trees for each bird. All graphs plot log response ratio (left to right) as a function of successive reinforcers. These data were in analyzed in the same manner as those in Figure 7, and use data from sessions 1-100. Due to a fewer number of sessions, trees were only plotted out to 3 (as opposed to 9) successive reinforcers. Filled circles connected with solid lines denote log response ratios obtained when confirmations occurred (consecutive reinforcers delivered for responding on the same alternative) and open circles connected with dashed lines denote log response ratios where disconfirmations occurred (a reinforcer delivered for responding on one alternative after consecutive reinforcers had been delivered on the other alternative).

The results of this analysis of smaller aggregates are similar to the findings in Figure 7. That is, responding before the first reinforcer is approximately equally distributed across the two alternatives and, as confirmations on a given alternative accumulate, preference for that alternative becomes more extreme. When disconfirmations occurred, log response ratios tended to shift back closely to the log response ratio at the beginning of a component; in some cases, a single disconfirmation shifted preference to the other alternative. Examining successive blocks of sessions, several interesting features take shape. Again, for all four birds, response patterns emerged quickly (within the first ten sessions). That is, confirmations resulted in more disparate ratios, causing the data points to separate from the origin, and disconfirmations drove log response ratios closer to ratios seen before confirmations had occurred or to more responding occurring on the alternative that had just delivered the reinforcer. Second, for two of the birds (280 and 49889) these response patterns did not change systematically across successive blocks of data. That is, as opposed to increasing or decreasing as a function of successive blocks of sessions, the shapes of the trees waxed and waned unsystematically. For birds 8418 and 17560,
a different pattern emerged. Examining successive blocks, log response ratios following confirmations increased across successive blocks of reinforcers. Similar to the other two birds, confirmations and disconfirmations produced the same results, but when examined across successive blocks of sessions, confirmations resulted in higher ratios between responding following a reinforcer.

Figures 21-28 show lag-regression analyses of sensitivity to reinforcer rate for individual subjects in blocks of ten sessions (session blocks are labeled as such in the top right corner). As in Figure 8, these were obtained via multiple-regression analyses. In all instances, sensitivity was highest for the reinforcer ratio currently in effect and shifts downward as a function of session lag. This indicates that within a given component, responding was primarily controlled by the reinforcer ratio currently in effect and not by the previous reinforcer ratios. For bird 280 there was an increase in sensitivity of responding to reinforcer rate across successive blocks of sessions. Bird 8418 also had an increased sensitivity estimate for the current reinforcer rate in effect, but additionally there was a decrease in control by the previous components reinforcer rates, as indicated by the decrease in sensitivity for lags 1, 2 and 3. Birds 17560 and 49889 also demonstrated decrease in control by previous reinforcer ratios in effect. For example, sensitivity estimates for the last 50 sessions are highest for the current reinforcer rate in effect and then control dropped quickly for reinforcer rates that were previously in effect.
Fig. 13. Log response ratios (left to right) for subject 280 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 1-50.
Fig. 14. Log response ratios (left to right) for subject 280 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 51-100.
Fig. 15. Log response ratios (left to right) for subject 8418 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 1-50.
Fig. 16. Log response ratios (left to right) for subject 8418 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 51-100.
Fig. 17. Log response ratios (left to right) for subject 17560 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 1-50.
Fig. 18. Log response ratios (left to right) for subject 17560 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 51-100.
Fig. 19. Log response ratios (left to right) for subject 49889 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 1-50.
Fig. 20. Log response ratios (left to right) for subject 49889 graphed as a function of successive reinforcers. Each graph represents different 10 session blocks for sessions 51-100.
Fig. 21. Individual subject data (280), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block.
Fig. 22. Individual subject data (280), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block.
Fig. 23. Individual subject data (8418), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block.
Fig. 24. Individual subject data (8418), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block.
Fig. 25. Individual subject data (17560), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block.
Fig. 26. Individual subject data (17560), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block.
Fig. 27. Individual subject data (49889), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block.
Fig. 28. Individual subject data (49889), sensitivity to reinforcer ratio graphed as a function of session lag. Each panel represents a different ten session block.
DISCUSSION

The current experiment sought to answer three separate questions. First, could findings similar to those of Davison and Baum (2000) be replicated outside of their laboratory? Second, would the structure of choice revealed with large aggregates of data remain intact with smaller aggregates? Third, how rapidly does performance in this preparation develop? These questions were tested by conducting Davison and Baum’s analyses (i.e., by examining sensitivity on a reinforcer by reinforcer basis and by characterizing preference pulses, response trees and lag analysis) at different levels of aggregation.

The first examination of data was an analysis of 35 sessions (i.e. sessions 15-50). This aggregate was chosen to replicate the findings of Davison and Baum (2000). There are very few published reports of these types of effects outside of their laboratory (see Aparicio, 2007; Aparicio & Baum, 2006). Furthermore, some attempts to replicate some of their findings have failed (Maguire, 2007). Nevertheless, the current findings suggest that the effects reported by Davison and Baum can be replicated in other laboratories. The data in Figures 2-5 are similar to Davison and Baum’s in that sensitivity of responding to relative reinforcement rate increased within a component as more reinforcers were delivered. These findings occurred for all 4 subjects within this experiment.

In addition to sensitivity changing in a similar manner as Davison and Baum (2000) research, other aspects of behavior allocation changed in a similar manner. First, as per Figure 6, preference pulses were preserved in the current experiment. In the current experiment, responding immediately after a reinforcer was emitted most frequently on the option that had just delivered reinforcement. In the response tree analysis (Figure 7), response ratios became larger
for the option that delivered several consecutive reinforcers (confirmations) and shifted towards equal responding if a reinforcer was then obtained via the other option (a disconfirmation). The lag analysis, shown in Figure 8, revealed that sensitivity was highest at lag 0 (the current component). This analysis also revealed some degree of carryover from the previous component (i.e., lag 1 values sometimes were greater than zero), but this effect tended to decrease across the course of the experiment (Figures 21-29). In general, sensitivity values at lag 2 and 3 were approximately zero, or less than zero. This indicates that responding is primarily controlled by the reinforcer rate currently in effect and to a lesser extent (lag 1), or not at all (lags 2 and 3), by reinforcer rates in previous components. Thus, the answer to the first question addressed by the current study was “yes.” The present data, aggregated over the last 35 sessions of the first 50-session segment, closely resembled those reported by Davison and Baum (2000, 2002, 2003, 2006, 2007).

To answer the second question addressed by the current study, the results of aggregating over smaller blocks of sessions revealed response patterns similar to those obtained with the larger aggregates. Figures 9 and 10 and Table 1 show sensitivity to reinforcer rate began at or near zero and increased as more and more reinforcers were accumulated within a component. In a similar manner, preference pulses were preserved across smaller aggregates, as were response trees (confirmations and disconfirmations). Finally, the lag sensitivity analysis revealed similar findings across the smaller aggregates of data. Thus, it appears that the structure of choice reported at a relatively large level of aggregation is preserved at smaller levels. The answer to the second question, are findings similar between large blocks of aggregates and small blocks of aggregates similar, appears to be “yes”. It should be noted that despite the size of the aggregates in this analyses, these data do not represent a true moment-by-moment analyses of choice.
Indeed, many of the analyses presented depend on log response ratios that are difficult to calculate on a reinforcer-by-reinforcer-basis, and impossible on a response-by-response basis. Analyses different from those presented here would be necessary to perform true local analyses.

The final question examined was, how rapidly did performance in this preparation develop? In the smaller aggregates of data, it appeared that the basic response patterns were generated within the first 10 sessions. Responding changed as a function of successive reinforcers. Response trees and preference pulses developed fairly quickly in this preparation, and lag analyses demonstrated the majority of responding was controlled by current reinforcer rates in effect as opposed to previous reinforcer ratios. These patterns developed relatively early in the experiment; in fact, patterns that emerged within the first 10 sessions persisted the entire course of the experiment.

The research conducted by Davison and Baum (2000, 2002, 2003, 2006, 2007) appeared to have at least two goals. One goal was to examine local effects utilizing molar analyses and the second is to investigate the nature of reinforcement. The results of the current study show that local effects (e.g., on a response-by-response or on a reinforcer-by-reinforcer basis) can be examined via molar analysis. This is not without a caveat though. Even though the data are plotted in a way that implies a response-by-response or a reinforcer-by-reinforcer analysis, is it necessarily the case that these data are representative? It is important to remember that these data are collected and analyzed using large aggregates, not individual responses or reinforcers. Indeed these analyses are nearly impossible (or at least very difficult) to perform on a truly response-by-response basis. It should be noted that the above analyses could have been performed in a truly molecular manner. Despite this, compelling evidence was generated demonstrating changes in responding in a rapidly changing environment on the “local” levels as
described by Davison and Baum. These data suggest that Davison and Baum’s data may not be a product of their aggregation. Indeed, some of the analyses are impossible to do on a true moment-by-moment basis, and new techniques need to be developed to examine aspects of allocation (e.g. sensitivity of responding) on a more local level.

Following from the data generated by Davison and Baum (2000, 2002, 2003, 2006, 2007) a theory was postulated that is difficult to explain via data alone. On the basis of their data, the authors’ claim that reinforcement theory needs to be retooled and that it was PIEs (not reinforcement) that controlled behavior in this preparation. This stance stemmed more from theoretical orientation than from data. Indeed, staying in line with Davison and Baum’s view of PIEs controlling behavior requires an examination of the theory guiding their research.

PIEs and Molar Analyses

In behavior analysis, two different levels of analyses are often used: molar and molecular. A molecular view contends that the optimal way to examine behavior is on a moment-by-moment basis. This type of analysis is a hallmark of classic behavior analysis, and this type of analysis has been effective in generating stable, reliable data. Controlling behavior are antecedent stimuli and consequences (e.g., reinforcers). Emphasis is placed on contiguity (e.g. the temporal relation) between a behavior and a consequence. The closer in time a behavior and a reinforcer, the higher the response strength will become. Further, if a consequence is delivered noncontingently (e.g., after a given duration of time and not dependent on a measure response), the response strength is weakened or extinction may occur (see Sizemore & Lattal, 1977).

In contrast, a molar view consists of analyzing data over extended periods of time. These time scales are relative and can consist of analyses carried out over the course of a single session
or can extend over the course of many sessions. While performing a molar analysis, aspects of 
the individual responses are lost, but overarching findings can lead to important theoretical and 
practical discoveries (e.g., the matching law). It is clear that a molar analysis is the type 
preferred by Davison and Baum in many of their papers (for a further discussion on the 
differences between molecular and molar analyses, see Baum, 2002).

According to Baum (2002), the notion of response strength stems from molecular 
analyses. Behavior is strengthened when members of a certain response class are reinforced (the 
more reinforcers, the more strength is associated with the given response class). Thus, the notion 
of strength cannot be assigned to one single response, but must be viewed relative to other 
responses; ergo, a class of responses is reinforced, not a single response. A molar view, in 
contrast, is concerned with behavior allocation within a given time space. For example, in a 24 
hrs period, one may spend 8 hrs sleeping, 8 hrs working, 4 hrs doing recreational activities, 3 hrs 
eating and an hr grooming himself/herself. Each of these broad activities can be said to have 
other activities “nested” in them (4 hrs of recreational activity may be broken down into 2 hrs of 
television viewing, 1 hour of listening to music and 1 hour of exercise), and these activities have 
further activities within them. Each of the groups of activities (be it the large blocks, the smaller 
blocks nested in them, or the still smaller blocks nested within them) can be considered a unit, 
depending on the question of interest.

In the same discussion (and in other commentaries: Baum, 1989; 2001), Baum argues 
that a molecular analysis is theoretically flawed (and with it the notion of response strength). 
There are two reasons he cites for this. The first is the notion of contiguity. Simply stated, 
contiguity involves two items being close together, for example spatially or temporally (in this 
case, temporally). For example, in a VI schedule, some responses are immediately followed by a
presentation of food (reinforcement). The statement could be made that there is contiguity between the response and food presentation, and one of the products is a strengthening of the response. The closer together in time the two events are, the greater the response strength.

Baum states this guiding metaphor of strength is dependent on the notion that behavior occurs in discrete events, beginning with a discriminative stimulus and ending with a consequence.

Further, a notion of a behavior and a consequence does not seem to be a “natural unit” as it is often thought of in behavior analysis (Baum & Rachlin, 1969).

In the above example of a VI schedule of reinforcement, it was mentioned that a specific response was reinforced, but to examine reinforcement, one has to examine a response class involving several responses and examine how responding changes as a function of reinforcer deliveries. Baum argues that response classes are abstract, meaning that one cannot point to a specific instance of reinforcement. For example, when observing a pigeon in an operant conditioning chamber, key pecks can be seen and eating food from a hopper can be seen (and both can be measured), but the reinforcement of a response class cannot be seen. A molecular account may counter that the process of reinforcement, by which a consequence increases the probability of a response class, can be seen. The strengthening effect of a reinforcer can be seen by the resulting change in response rate. Baum argues the process of reinforcement is assumed due to a change in allocation of responses, leading to increased response rate and a higher probability of responding. Further by Baum’s distinguishes between a class and an individual. This appears to be analogous to the notion of a species and an individual; a cow (individual) can be seen on the side of the road, but the species Bos taurus cannot be seen. Also important to Baum’s modern molar argument is the notion that an individual can change over extended time periods. For example a calf, over a period of time, turns into a cow. Species do not change; as
differential traits are selected by the environment and change occurs in the species, the species classification does not change; but a new species is created (e.g., *Homo erectus* becoming *Homo sapiens*).

Behavior can be thought of in this context. An individual unit can be considered time allocation (for the sake of a molar analysis). In an operant conditioning chamber, equipped with two keys for a pigeon to respond, a pigeon (trained to key peck) may begin to allocate its responses somewhat indiscriminately. If reinforcers were 5 times more likely to be delivered on one key then on another, different response patterns would likely begin to emerge favoring the response key that delivered 5 times the reinforcement (i.e., matching). In this case, allocation of responses (the individual) changed, whereas from a molecular account a new response class (species) would emerge (according to Baum, 2002). Skinner also makes a point of distinguishing between a class and an individual (referred to as an instance).

An operant is a class, of which a response is an instance or member… it is always instances which are counted in determining frequency, and from that frequency the probability of a response inferred. The probability is frequently taken, however as the measure of the strength of an operant (p. 131, Skinner, 1969).

The distinction between classes and individuals is very important for understanding the concept of PIEs. From a molar stance (particularly from Baum’s molar stance), reinforcement is inadequate in explaining behavior, as the traditional notion of reinforcement is based on response classes that rely on the notion of strength, which can only be viewed through abstraction. When removing the notion of strength, what is left in the consequence to control behavior? The answer according to Davison and Baum (2006) is the remaining property of the reinforcer. This would
be the notion that a reinforcer serves only as a stimulus. This stimulus could be considered signaling delivery of additional PIEs. Davison and Baum (2006) state,

…phylogenetically important events, such as food and pain, will guide behavior into activities that produce fitness enhancing events and into activities that prevent the fitness reducing events. (p. 281).

Hence, reinforcer delivery is merely guiding behavior towards an option that will provide additional reinforcers (or PIEs to use Davison and Baum’s nomenclature). Viewed in Baum’s molar analysis, the notion of strength is supplanted by the notion of behavior allocation. As more and more PIEs are delivered as consequences, behavior or time is allocated across the different options as a function of deliveries of these events.

Experimental Data

For the current data set, data were analyzed using two different levels of aggregation, 35-session blocks and 10-session blocks. The purpose of the 35 block aggregation was to replicate the findings of Davison and Baum (2000). The current findings support that their data can be replicated outside of their laboratory. Additionally aggregates of 10 sessions were analyzed and the same general findings were found across these smaller blocks. Indeed the findings across both aggregates are similar to those of Davison and Baum, but does this confirm their notion that the delivery of food serves only as a stimulus and does not strengthen behavior?

It is difficult to determine an answer to this question with the present data. Indeed, one could note that a reinforcer did function merely as a stimulus, guiding behavior towards the just productive alternative (as demonstrated in the preference pulses), but it should also be noted when there appeared to be some strengthening effects of the consequence as well. Pulses shifted closer to equal responding, but never actually reached an asymptote at zero or below zero. This
continued preference for the just-productive alternative (which likely was the richer alternative) can be conceptualized as a strengthening effect. This is, even though “P” responding after a reinforcer was extremely high, after the pulse reached its asymptote, it was more probable that a “P” response would still be emitted. Besides preference pulses, another sign of strengthening can be found in the sensitivity estimates. Within-component obtained reinforcer ratios did not match programmed reinforcer ratios. In fact, in several of the components (e.g. 27:1, 9:1, 1:9, and 1:27), reinforcers were often obtained exclusively on the rich side. A specific response class may have been created out of this. This response class would be continual responding on the side that had just delivered reinforcement. In all components, save for the 1:1 component, once a reinforcer has been obtained via one alternative, it was more probable that responding on that same alternative would produce more food than switching to the other alternative. This indicates that a response class of “staying” could have been created by the contingencies in effect and that switching to the other alternative would be reinforced infrequently.

Additionally, a mixed schedule was in effect; there was no signal indicating which alternative was the rich or lean component in a session. This would account for sensitivity to reinforcer rate being low at the beginning of a component and rising as a function of successive reinforcer deliveries. Once several deliveries of food had been obtained within a component, responding began to approximate matching. These contingencies seemed to have created a situation in which staying on one alternative was strengthened, and the responding followed accordingly.

An additional point is how quickly acquisition of this type of responding took place. The basic structure of choice emerged within the first block of 10 sessions (included in this analysis and excluded in previous research). That is to say, sensitivity of responding to reinforcer rate,
preference pulses, and the pattern illustrated by the response trees emerged during this time and, for the most part, persisted with little deviation. At least two alternatives are possible. One is that the signaling effects of PIEs emerge rapidly, and their discriminative function caused behavior to be allocated in response patterns that would persist throughout the experiment. The alternative is that a response class in which continued responding on the alternative that had just paid off could develop as quickly. Skinner (1938) noted that even without conditioning, reinforcement can generate dramatic increases in response rate (i.e., strengthen responding). Further, Skinner argued that speed of acquisition of a response can be a measure of strength.

Probability of response is also sometimes inferred from how quickly the response is acquired or brought under stimulus control. If a response of complex topography is acquired only slowly, it is assumed that it began in very low strength… (Skinner, 1969). Following from this, it could be inferred that if a complex topography can be learned very quickly, it is a case of very high strength. Acquisition of response patterns emerged quickly in this situation, which may be an indication of reinforcer strength. Thus, of the two alternatives (molar or molecular), the one selected seems to depend more on theoretical orientation than on the presentation of the data.

Limitations

Though this preparation is convenient for examining choice and rapid acquisition of behavior, it is not without its flaws. The first involves the choice of component ratios and its potential effects on response allocation. During each session, a probability gate was sampled to determine which option delivered reinforcement, and 10 reinforcers were delivered per component. In four of the components (27:1, 9:1, 1:9, 1:27), a reinforcer was rarely delivered on the lean alternative. Essentially, this created components in which one alternative provided 10
reinforcers and the other provided 0 reinforcers. This could be considered extinction of responding on the lean alternative, in four of the seven components. This may create a situation where, regardless of the component, a subject continually responds on one alternative after receiving reinforcement from that alternative. In terms of the analysis, a phenomenon such as the preference pulses in the above results, and in Davison and Baum’s (2003, 2004, 2006, and 2007) studies, may have resulted simply because several of the components within a session involved extinction. Further, these components may have affected responding in the remaining three components. A potential for future research would be to create a condition in which instead of arranging extinction of responding on the lean alternative, each component contained at least one reinforcer delivery by the lean alternative.

Another issue also involves the more disparate components in this preparation. Many times the obtained reinforcer ratio was not able to be calculated due to the occurrence of a zero in either the numerator or the denominator. Because of this, the overall obtained reinforcer ratio was substituted. For example, if no reinforcer occurred in the 27:1 component during session block 31-40, the log reinforcer ratio for sessions 1-50 were substituted. Although this practice was preferred over using the programmed reinforcer ratio (27 divided by 1), it did not involve the actual obtained reinforcer ratio a given 10 session block. This is another problem that could be solved by programming contingencies in which at least one reinforcer is delivered from both alternatives within each component.

A third issue of the present study is that the method of analyses and data presentation may be deceptive. Although orderly, these analyses do not actually show what occurred on a moment-by-moment basis. For example, reinforcement was shown to change as a function of reinforcers (e.g., see Figures 2-5 and 10), but from these figures it is not clear what was
occurring on a moment-by-moment basis, as these data are aggregated across 35 or 10 sessions. It is very difficult, perhaps impossible, to conduct these sort of analyses (i.e., sensitivity based upon log ratios of responses and reinforcers) on a true reinforcer-by-reinforcer basis.

Finally, these analyses could be considered to be a sort of molar analyses of molecular events. Analyses such as the generalized matching equation are molar analyses and can only be conducted using aggregates. To ascertain what is occurring on a truly moment-by-moment basis would require a different type analyses.

Conclusions

The data from the current study replicated the results of Condition 1 of Davison and Baum’s (2000) study. Sensitivity of responding to reinforcer ratio increased as a function of successive reinforcers and preference pulses emerged. Further, the response-tree analysis revealed that as more and more confirmations occurred, log response ratios moved in an outward direction from the first response, and a single disconfirmation shifted responding close to its starting point. Finally, responding was controlled mainly by the current reinforcer ratio in effect and not the previous component’s reinforcer ratio (lag analysis). The results of the smaller aggregates were similar to the larger aggregate findings. An interesting finding was the speed at which response patterns emerged. For most cases, response patterns were occurring within the first 10 sessions.

Whether these data (or those of Davison and Baum) show definitive evidence that the notion of reinforcement is antiquated and needs to be replaced remains to be seen. At the current time, Davison and Baum’s PIEs seem premature. The current findings could indicate that reinforcement has dynamic properties that can change rapidly and that strengthening (i.e., increased probability of responding) can occur within a few reinforcers. It would be difficult to
confirm the theory of PIEs. However, although this view do not leave room for the notion of reinforcement, or for molecular analyses, this does not necessarily mean that fruitful data cannot be found by analyzing data on a response-by-response basis. Indeed, it is these response-by-response and reinforcer-by-reinforcer events that feed into the extended behavior allocation that is studied in a molar analysis and in a way are required to examine behavior in a molar manner. The answer to the notion of whether PIEs or reinforcement is the best way to conceptualize effects of contingencies may not to be a question that can be answered by data analysis, but answered in terms of theoretical orientation.
References


