PREFERENCE REVERSAL AND THE ESTIMATION OF INDIFFERENCE POINTS
USING A FAST-ADJUSTING-DELAY PROCEDURE WITH RATS

By

SHONNIE M. BENNETT

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE
UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2002
ACKNOWLEDGMENTS

I thank my committee members (Dr. Marc N. Branch, Dr. Timothy Hackenberg, Dr. Joanna Peris, Dr. Donald J. Stehouwer, and Dr. Timothy Vollmer) for their assistance in the completion of this dissertation. I express sincere thanks to Cynthia Pietras, Manish Vaidya, Stephen Haworth, and Rafael Bejarano for their continuous support and numerous helpful discussions. Finally, I am greatly indebted to Dr. Frans van Haaren for his assistance and guidance throughout all phases of the development and preparation of this dissertation.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td><strong>CHAPTER</strong></td>
<td></td>
</tr>
<tr>
<td>1 GENERAL INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2 EXPERIMENT 1</td>
<td>11</td>
</tr>
<tr>
<td>Introduction</td>
<td>11</td>
</tr>
<tr>
<td>Methods</td>
<td>12</td>
</tr>
<tr>
<td>Subjects</td>
<td>12</td>
</tr>
<tr>
<td>Apparatus</td>
<td>12</td>
</tr>
<tr>
<td>Procedures</td>
<td>13</td>
</tr>
<tr>
<td>Results</td>
<td>18</td>
</tr>
<tr>
<td>Discussion</td>
<td>23</td>
</tr>
<tr>
<td>3 EXPERIMENT 2</td>
<td>25</td>
</tr>
<tr>
<td>Introduction</td>
<td>25</td>
</tr>
<tr>
<td>Methods</td>
<td>27</td>
</tr>
<tr>
<td>Subjects</td>
<td>27</td>
</tr>
<tr>
<td>Apparatus</td>
<td>28</td>
</tr>
<tr>
<td>Procedures</td>
<td>28</td>
</tr>
<tr>
<td>Results</td>
<td>33</td>
</tr>
<tr>
<td>Discussion</td>
<td>88</td>
</tr>
<tr>
<td>4 GENERAL DISCUSSION</td>
<td>94</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>109</td>
</tr>
<tr>
<td>BIOGRAPHICAL SKETCH</td>
<td>115</td>
</tr>
</tbody>
</table>
Self-control was defined as choice of a large, delayed reinforcer over a small, more-immediate one. Rats in Experiment 1 were presented with a choice between a small, immediate reinforcer (one pellet delayed by 0.1 s) and a large, delayed food reinforcer (three pellets delayed by 6, 12, 24, or 48 s). The purpose of this experiment was to determine if preference for the large reinforcer would reverse when the delay to the large reinforcer (three pellets) was increased across experimental conditions. When rats were presented with a choice between one pellet after 0.1 s and three pellets after a 6 or 12 s delay, five of the six subjects chose the large, delayed reinforcer. Preference reversed to almost exclusive choices for one pellet delayed by 0.1 s when the delivery of three pellets was increased to 48 s. The discrete-trial procedure used in Experiment 1 provided data for interpolating the large reinforcer delay producing a preference reversal as somewhere between 24 and 48 s. The purpose of Experiment 2 was to examine the use of a fast
adjusting-delay procedure to precisely determine the delay to the larger reinforcer that would result in preference reversal. This was achieved by adjusting the delay to the large reinforcer (three pellets) dependent upon the subject’s performance across choice trials. The standard alternative of one pellet followed a fixed delay of 0.1, 2, 4, 8 or 16 s. The adjusted delay that maintained equal responding between the two alternatives defined the indifference point and the delay at preference reversal. The indifference points increased as the delay to the small reinforcer increased suggesting increased preference for the large, delayed reinforcer as the delay to the small, immediate reinforcer increased. Linear regression analyses of the resulting discount functions yielded positive slopes that were very similar to those previously reported using other subjects and procedures. Although the y-intercepts generated from the current experimental findings were larger than those previously reported using pigeon subjects. The findings from Experiment 2 were consistent with those from Experiment 1. Consistent with previous findings, the current findings provide support for a hyperbolic equation of choice.
CHAPTER 1
GENERAL INTRODUCTION

Self-control choice has been defined as choice of a large, delayed reinforcer over a small, immediate one; impulsive choice was defined as the opposite (see review by Logue 1988). The current experiments investigated the influence of increased large, reinforcer delays on self-control choice of rats. Previous self-control research with human and non-human subjects has produced a number of consistent experimental findings. First, pigeons have been shown to make impulsive choices for food reinforcers when the small reinforcer is immediately available. That is, pigeons will choose 2 s of grain access now over 6 s of grain access after a 6 s delay (Ainslie 1974; Logue 1988; Logue and Mazur 1981; Logue, Rodriguez, Peña-Correal, and Mauro 1984; Mazur and Logue 1978; Rachlin and Green 1972). Rats have also been shown to make impulsive choice under similar choice conditions (Eisenberger and Masterson 1987; Eisenberger, Masterson, and Lowman 1982; Evenden and Ryan 1999; Tobin, Chelonis, and Logue 1993). While self-control choice patterns are generally reported with humans and sometimes with rat subjects (King and Logue 1987; Logue, King, Chavarro, and Volpe 1990; Logue, Peña-Correal, Rodriquez and Kabela 1986; Takahashi and Fujihara 1995; van Haaren, van Hest, and van de Poll 1988). Further investigation determined that several procedural variables may have contributed to the higher percentage of self-control choices observed with human subjects (Flora, Schieferecke, and Bremenkamp 1992;
Forzano, Porter, and Mitchell 1997; Green, Fry, and Myerson 1994; King and Logue 1987; Logue 1988; Logue et al. 1990; Logue et al. 1986; Millar and Navarick 1984; Navarick 1986; Takahashi and Fujihara 1995). Most research examining human self-control choice has included the presentation of choices between hypothetical amounts of money or points exchangeable for money. Points that are earned within a session are typically exchanged for money at the end of an experimental session or following some post-session delay. Pigeons made more self-control choices when this type of second-order arrangement was utilized. Jackson and Hackenberg (1996) presented pigeons with self-control choices for tokens (the presentation of light emitting diodes) that could be exchanged for food after the completion of several or all of the choice trials in a session. The data suggested that higher self-control responding was observed in this choice arrangement due to the similarity of delays to food for choosing either alternative. Furthermore, the use of consumable or primary reinforcers such as access to a video game, pictures, or loud noise presentation have been shown to result in more impulsive choice by humans (Flora et al. 1992; Forzano et al. 1997; Millar and Navarick 1984; Navarick 1986). Collectively, these data suggest that the use of conditioned or specifically token reinforcers that are only exchangeable at the end of a session may result in more self-control choice than when primary reinforcers are used. Notably, a study reported by van Haaren et al. (1988) demonstrated high percentages of self-control choices in rats utilizing consumable reinforcers. In Experiment 1, van Haaren et al. (1988) showed that rats made self-control choices when presented with a choice between 3 pellets available after a 6 s delay and one pellet available after a 0.1 s delay. However, these subjects had previously been exposed to choices between equally delayed (at 6 s)
but unequal amounts of food (1 versus 3 pellets) before exposure to the self-control choice arrangement. This history may have biased preferences. Even if the initial exposure to equal delays was a variable that contributed to the observed preference of these rats, this finding is still inconsistent with findings reported with pigeons. They require an extensive history of gradual changes in the delay to maintain even a small percentage of self-control choice when the small reinforcer is immediately available (Logue and Mazur 1981; Logue et al. 1984; Mazur and Logue 1978). The delays were not gradually faded in Experiment 1 of van Haaren et al. (1988) but instead decreased from six seconds to a 0.1 s delay to one pellet. Tobin et al. (1993) showed that a similar history of equally delayed but unequal amounts of reinforcement was not sufficient to maintain self-control choice in rats. Rats were initially presented with a choice between two seconds versus six seconds of access to sweetened condensed milk before the delay to the small reinforcer was decreased to zero seconds. Less than thirty percent of the choices were for the large, delayed reinforcer. Thus, the possibility remains that rats would make self-control choices even without this brief history of delayed reinforcement in a choice arrangement similar to that used by van Haaren et al. (1988).

Another defining feature of self-control choice with humans and nonhumans is preference reversal from the small to the large reinforcer with increased delays to both alternatives (Ainslie 1974; Fantino 1977; Ito and Asaki 1982; Logue 1988; Navarick and Fantino 1976; Rachlin and Green 1972) or from the large to the small reinforcer with increased large reinforcer delays (Green, Fristoe, and Myerson 1994; Logan 1965; Logue 1988; van Haaren et al. 1988). Preference reversals have been examined using two types of experimental procedures. In the fixed procedure, subjects are presented with a choice
between a small, more-immediate reinforcer versus a large, delayed one and the delay to one or both alternative is manipulated across conditions. The delay producing a switch in preference is then interpolated across conditions. An example of increasing the delay to both alternatives comes from an experiment reported by Rachlin and Green (1972). Pigeons chose a small, immediate food reinforcer over a large, delayed one until an opportunity to make a commitment response was provided at a point before the choice opportunity. The pigeons could make a commitment response by completing twenty-five responses (FR 25) on one of two response keys prior to the presentation of a choice between an immediate but small reinforcer and a large but delayed reinforcer. Completion of the ratio on one key resulted in the presentation of only the large, delayed reinforcer alternative during the choice component while completing the ratio on the other key resulted in the presentation of both choice options. The addition of this commitment opportunity resulted in increased self-control choice.

A second type of fixed procedure was demonstrated in Experiment 2 by van Haaren et al (1988). Rats were presented with a choice between one pellet delayed by 6 s and three pellets following a delay ranging from 9 to 36 s. The delay to three pellets increased across conditions and the subjects did not make impulsive choices until the delay to three pellets was 36 s. The data showed that a preference reversal would require a large, reinforcer delay in excess of 36 s.

The second type procedure used to predict preference reversals by determining the indifference point is an adjusting or titrating procedure. In this arrangement, the delay or amount of reinforcement changes/adjusts due to the subject’s preference (Bickel, Odum, and Madden 1999; Mazur 1987; 1988; Richards, Mitchell, de Wit, and Seiden
Mazur (1987) introduced the use of an adjusting delay procedure to examine changes in the value of delayed reinforcers in a self-control choice arrangement. In this procedure, pigeons chose between a standard or adjusting alternative. Choice of the standard alternative resulted in a small reinforcer, 2 s of access to grain, after a fixed delay (0, 1, 2, 6, 10, 14, or 20 s). Choice of the adjusting alternative resulted in a large reinforcer, 6 s of grain access, after a delay that changed based on the subject’s choices during a session. A block of trials started with exposure to each alternative followed by two choice trials. Based on the choices made during that block, the delay to the large reinforcer changed during the next four-trial block. If the subject chose the large reinforcer during the two choice trials, then the delay to that reinforcer increased by 1 s during the next block of trials. However, if the subject chose the small reinforcer during the two choice trials, the delay to the large reinforcer was decreased by 1 s during the next block of trials. Finally, if the subject made one choice for each alternative, the delay to the large reinforcer did not change during the next trial block. The point of indifference was defined as the delay at which the subject responded equally often on both choice alternatives.

Examining changes in the indifference point with changing delays to the small reinforcer allowed experimenters to fit equations to these data which quantify changes in reinforcer value with increased delays to their receipt (the discount function). Indifference curves, plots indifference points as a function of increased standard delays, are then described with the parameters associated with the best fitting lines (the discount function). One major advantage of the adjusting procedure is that the delay at preference reversal can be determined more rapidly, within an experimental condition as opposed to
across several experimental conditions. A second advantage is the sensitivity of the procedure to individual (across) subject variability and to within subject changes in preference. The performance of each subject produces changes in the delay to the adjusting alternative. If a subject is sensitive to reinforcer delays, the adjusting delay decreases accordingly until responding maintains for each choice alternative. The opposite pattern of adjustment would be observed with a subject that is not sensitive to reinforcer delays. Finally, the delay producing a reversal of preference can be narrowly defined instead of interpolated across conditions. Richards et al. (1997) provided a modification of this procedure where the amount of immediate reinforcement adjusted across choice trials instead of the delay. The procedure included several other modifications designed to allow for a much more rapid determination of indifferences points than Mazur’s adjusting-delay procedure. Currently, the procedure proposed by Richards et al. (1997) has not been systematically replicated to determine if stable indifference points could be rapidly determined when the procedure included an adjusting delay instead of the adjusting amount. Experiment 2 was designed to systematically replicate the procedures proposed by Richards et al. (1997) when the delay adjusts.

Mazur (1987) proposed a hyperbolic function to describe how the value of a choice alternative is influenced by reinforcement parameters. This equation has been used to successfully describe self-control choice behavior across species and fixed or adjusting procedures (Ainslie 1974; Bickel et al. 1999; Green, Fristoe, and Myerson 1994; Green, Fry, and Myerson 1999; Green, Myerson, and McFadden 1994; Ho, Wogar, Bradshaw, and Szabadi 1997; Mazur 1987; 1988; Mazur et al. 1987; Rachlin and Green

\[
V(x) = \frac{R}{x + a}
\]

where \(V(x)\) is the value of the choice alternative, \(R\) is the reinforcer value, and \(a\) is a parameter that reflects the subject’s sensitivity to delay. This function has been used to successfully describe self-control choice behavior across species and fixed or adjusting procedures...
1972; Richards et al. 1997; Richards et al. 1999; Tobin, Chelonis, and Logue 1993). The equation is:

\[ V = \frac{bA}{1+KD} \]  

(1-1)

describing changes in the value of a reinforcer as a function of reinforcement parameters of amount and delay. In this equation, A is a parameter that is monotonically related to the amount of reinforcement, D is the delay to its receipt and K is a discount parameter that is empirically determined for each subject. The equation describes value/preference for a given alternative to be a direct function of the amount of reinforcement and inversely related to the delay. The equation sometimes included a bias parameter, b, to describe consistent preference for one alternative irrespective of reinforcement parameters. Furthermore, the adjusted delay at indifference can be predicted by setting the equations for each alternative equal to each other such as:

\[ \frac{A_L}{1+KD_L} = \frac{A_R}{1+KD_R} \]  

(1-2)

The subscripts of L and R designate the parameters associated with the left and right response alternatives, respectively. For illustration, the bias term is set equal to 1.0, assuming no response bias.

Several predictions regarding choice behavior follow from this equation. First, the equation predicts a preference reversal. Second, the equation predicts a linear relation between the adjusting delay at indifference as a function of increased standard delays with a y-intercept greater than one and a positive slope. Experimental evidence supported the predictions of this equation (Ainslie 1974; Green, Fristoe, and Myerson 1994; Green, Myerson, and McFadden 1997; Ho, Mobini, Chiang, Bradshaw, and Szabadi 1999; Logan 1965; Logue 1988; Mazur 1987; 1988; Mazur et al. 1987; Rachlin...
and Green 1972; Richards et al. 1997; Richards et al. 1999). Although, the difference in choice behavior of pigeons and the findings with rats reported by van Haaren et al. (1988) may suggest that the influence of delays on the reinforcer value is qualitatively different for rats and pigeons, similarities in the observed discount functions suggest qualitative similarity but instead leave the possibility that the differences are quantitative in nature. An evaluation of discount functions would provide data to address this issue. If the observed differences in self-control choice across species was in fact due to some qualitative differences in how delays for reinforcement influence reinforcer value, then the discount functions would be expected to have different forms and be inconsistent with the predictions of the hyperbolic equation. Alternatively, if the differences were quantitative in nature, the functions would be expected to look similar in form but differ in the absolute parameters associated with the function.

The adjusting-delay procedure proposed by Mazur produced data describing how delays to reinforcer delivery influenced reinforcer value or preference. Experimental research has demonstrated that as the delay to the small reinforcer increased, the mean adjusting delay to the large reinforcer increased at the point of indifferent responding between the two alternatives. One equation that has accurately described this relationship was a hyperbolic discounting equation. Although this procedure has been successfully used to examine discount functions across species, one limitation of the procedure is the lengthiness of producing the indifference curve. Richards et al. (1997) proposed a procedure to examine the influence of changing reinforcer amounts on indifference points with a procedure that rapidly determined the indifference curve. The indifference curves reported by Richards et al. (1997) described how changes in reinforcer amount influenced
reinforcer value instead of how reinforcer delay did as in the Mazur (1987) procedure. Extending the procedures of Richards et al. (1997) to an adjusting delay procedure may allow rapid determination of indifference curves with rats and provide data illuminating similarities and/or differences in such said function between rats and pigeons. As previously noted, rats have been reported to make self-control choices in conditions where pigeons make impulsive ones suggesting a potential qualitative difference in the delay discount functions from rats to pigeons. The purpose of the current experiments was not to examine species differences per se although the data illuminate whether the reported differences between the performance of rats and pigeons is the result of quantitative or qualitative differences in the delay discount functions. Examination of the delay discount functions with rat subjects would provide evidence regarding this possible account.

The systematic replication of the procedures proposed by Richards et al. (1997) provide delay discount functions with rats that have not previously been reported in the self-control choice literature (see review by Logue 1988). Furthermore, the data will extend previous reports of delay discount functions reported with pigeon (Mazur 1987; 1988) and human subjects (Rachlin, Raineiri, and Cross 1991; Richards et al. 1999).

In summary, comparisons of self-control choice between rats and pigeons leave several questions to be addressed: First, was the history provided to subjects in Experiment 1 of van Haaren et al. (1988) responsible for the observed self-control with rats that has not typically been observed with pigeon subjects? Secondly, if the subjects show near exclusive self-control choice without such a history, what are the large, reinforcer delays at which rats make impulsive choices? Thirdly, will discount functions
obtained using rats in a modified fast adjusting-delay procedure proposed by Richards et al. (1997) be qualitatively similar to those observed with pigeons using Mazur’s (1987) adjusting-delay procedure? Finally, will the modified procedure of Richards et al. (1997) provide delay discount functions that are similar to those observed using other subjects and using the standard adjusting delay procedure?
CHAPTER 2
EXPERIMENT 1

Introduction

As previously noted, pigeons typically make impulsive choices when presented with a choice between a small, immediate reinforcer and a large, delayed one unless they have been provided with an extensive history of gradually changing delays (Ainslie, 1974; Logue and Mazur, 1981; Logue 1988; Logue and Mazur 1978; Logue et al. 1984). The findings reported from Experiment 1 by van Haaren et al. (1988) suggest that rats may not require a history of gradually changing delays to maintain preference for the large, delayed reinforcer when a small one is immediately available. Other researchers have reported impulsive choice patterns using rats (Eisenberger and Masterson 1987; Eisenberger, Masterson, and Lowman 1982; Evenden and Ryan 1999; Tobin, Chelonis, and Logue 1993). Tobin et al. (1993) reported impulsive choice with rats even after being provided with a history similar to that provided by van Haaren et al. (1988). These findings suggest that a history with delayed reinforcers may not be sufficient to obtain the exclusive self-control choice that were observed with rats by van Haaren et al. (1988). The inconsistent experimental findings are not attributable to different durations of history as subjects in both experiments were provided with similar durations of exposure to the choice arrangement in terms of number of sessions and the number of trials per session. The first question addressed in the present experiment was whether the history provided the rats in Experiment 1 of van Haaren(1988) was necessary to obtain the self-control choice preferences observed. The subjects in the current experiment were not
provided with a history of delayed reinforcement before self-control choices were examined. The second goal was to determine the large, reinforcer delay that would be required to obtain a switch in preference from the large reinforcer to the small reinforcer as determined using a fixed procedure.

Methods

Subjects

The subjects were three male and three female experimentally naïve Wistar rats. Female rats weighed 334 grams and male rats weighed 464 grams at the start of the experiment. The subjects were housed in same-sex groups of three per cage. Water was continuously available but access to food was restricted to a daily total of 36 grams for female subjects (12 grams per female) and 45 grams for male subjects (15 grams per male), presented immediately after the experimental session or at approximately that time of day on weekends. This daily feeding regimen allowed approximately 22 hours of food deprivation at the start of each experimental session. Rats were housed under a reversed light cycle (lights on at 7:00 p.m. and off at 7:00 a.m.); experimental sessions were conducted during the dark cycle between 11:00 a.m. and 1:00 p.m. on Monday through Friday.

Apparatus

All experiments were conducted in three identical standard rodent operant chambers that were 30 cm long, 25 cm wide, and 29 cm high (Coulbourn Instruments, Allentown, PA). The floor of each chamber consisted of 16 metal rods, spaced 1.75 cm apart. The two sidewalls were made of Plexiglas while the front experimental panel and back wall were made of stainless steel. The experimental panel consisted of two
nonretractable response levers, stimulus lights above each lever, and a centrally located food dispenser and houselight. The houselight was located 3 cm from the chamber ceiling and provided diffuse illumination. The pellet tray was located 1.7 cm from the floor and was illuminated during pellet presentation (Noyes, 45-mg rodent formula P). The response levers were located 12.5 cm apart and 6.3 cm above the grid floor. Each lever required a force exceeding 0.20 N to close a microswitch. Each chamber was enclosed in a sound-attenuating and ventilated cubicle. Experimental events were controlled and data collected using a PDP 11-23 microcomputer (Digital Equipment Corporation) and SKED-11 programming software (Snapper and Inglis, 1981).

**Procedures**

**Preliminary training.** Each session started with a dark period of 10 minutes during which lever presses had no programmed consequences. Once the houselight and stimulus lights above each lever were illuminated, pellets were delivered according to a conjoint fixed ratio (FR 1) of one response (responding on either lever could satisfy this contingency) and a variable time (VT) 60 s schedule of delivery (van Haaren, 1992). Sessions lasted for 45 minutes or until 40 reinforcers had been presented, whichever occurred first. Once subjects reliably responded on both levers (as determined by visual inspection of the data), the VT schedule was eliminated and lever presses were reinforced on a FR 3 schedule. During this part of training, the fixed-ratio schedule was correlated with only one lever at a time and was signaled by illumination of the stimulus lights above that lever. The “active” lever was alternated after five reinforcers were delivered. The strict alternation between the two levers ensured equal responding and equivalent histories of reinforcement for responding on both levers.
General experimental procedures. Each session started with a dark period of ten minutes as used in preliminary training. Each session consisted of two trial types: forced exposure trials and choice trials. A session started with forced exposure to both choice options but the order of their presentation was randomly determined at the beginning of each session. The remaining forced exposure trials for the large reinforcer (three pellets) were then presented on trials 5, 8, 12, and 20 while forced exposure trials for the small reinforcer (one pellet) was presented on trials 6, 10, 16, and 24. Figure 1 shows the arrangement of stimulus lights and the sequence of stimulus changes during a given trial. A trial was initiated with the illumination of the houselight and stimulus lights above the lever(s). One set of stimulus lights was illuminated continuously and the other set of stimulus lights blinked (on/off cycle of 0.75 s/0.1 s). Completion of three consecutive responses (FR3) on the lever associated with blinking stimulus lights extinguished all stimulus lights and initiated a delay to pellet presentation that was signaled by a blinking houselight (HL)(on/off cycle of 0.75 s/0.1 s). Completion of the FR3 on the lever associated with continuous stimulus lights extinguished all stimulus lights and initiated a delay to pellet presentation signaled by continuous illumination of the houselight (HL). A pellet was always presented simultaneously with the illumination of the food receptacle. For the large amount of food, two additional pellets were delivered at 1 s intervals. The food receptacle was illuminated for 2 s for both reinforcers. Completion of pellet delivery initiated the intertrial interval (ITI), during which all chamber lights were extinguished. Trials were scheduled to start every 60 s if at least 10 s had elapsed since the beginning of the intertrial interval. If the 10 s minimum requirement was not met, the next trial began after another 60 s had elapsed. Each session lasted 45 minutes.
Figure 1. Diagram of events during a trial. Sequence of stimulus presentations in a choice trial. The sequence begins at the top of the diagram showing the delay between a choice and food delivery followed by a blackout until the next trial begins.
or until completion of 34 trials (10 forced and 24 free-choice trials), whichever occurred first.

**Delay conditions.** The delay to the delivery of one pellet was scheduled at 0.1 s while the delay to the delivery of three pellets was systematically manipulated across experimental conditions. Table 1 shows the order of experimental conditions as well as the number of sessions that subjects were exposed to each delay condition. For five out of six subjects the delay to three pellets was 6, 12, 24, 0.1, 24, 0.1, and then 48 s across conditions. The delay to three pellets was 6, 3, 6, 0.1, 24, 3, and then 6 s for subject 132F.

All of the subjects were initially presented with a choice between one pellet delayed by 0.1 s and three pellets delayed by 6 s. The contingencies associated with the two levers were reversed as each subject’s performance reached the stability criteria. For five subjects, the delay to three pellets was then increased to 12 s and the delay to one pellet remained at 0.1 s. As each subject’s performance met the stability criteria, the contingencies associated with each lever were reversed. The stimulus lights remained the same but the lever associated with each alternative switched during a contingency reversal. In other words, three pellets may be presented following responses on the right lever with a flashing stimulus array during one condition but follow responses for the left lever with fixed stimulus lights in the contingency reversal condition. The delay to three pellets was then increased to 24 s while the delay to one pellet remained at 0.1 s for one pellet. Again, the contingencies were reversed as performance became stable. The delay to three pellets was then decreased to 0.1 s making the delay equal to that for one pellet. The contingencies were reversed as each subject’s performance became stable before the
delay to three pellets was again increased to 24 s. The contingencies associated with each lever were reversed as each subject’s behavior met the stability criteria. The delay to both alternatives was then made equal at a 0.1 s delay and the contingencies associated with each lever was also reversed at the same time. This is the first condition in which two changes were made in the same condition; the delay and contingency associated with each lever were both changed. The delay to three pellets was then increased to 48 s. During this condition, five subjects were choosing between three pellets delayed by 48 s and one pellet delayed by 0.1 s. The delay to three pellets was then decreased to 24 s before the contingencies associated with each lever were reversed.

Subject 132F was provided with a different history. When subject 132F was presented with a choice between three pellets delayed by 6 s and one pellet delayed by 0.1 s, the percentage of choices for three pellets was almost zero. The delay to three pellets was then decreased to 3 s until the stability criteria were met and the contingencies associated with each lever were reversed. The delay to three pellets was then increased to 6 s and the contingencies associated with each lever were reversed after performance became stable. The delays were both 0.1 s during the next condition before the contingencies were again reversed. Due to a programming error, the delay to three pellets was then increased to 24 s. The delays were then made equal at 0.1 s during the next condition before the delay to three pellets was increased to 3 s. The delay to three pellets was then increased to 6 s and the contingencies were again reversed when the performance met criteria.

**Stability criteria.** Several stability criteria were met before experimental conditions were changed. The percentage of choice trials in which subjects chose the
large, delayed reinforcer over the small, immediate reinforcer was used to determine stability. First, a minimum of 10 sessions was required in each experimental condition.

Table 1. Delay Conditions in Experiment 1

<table>
<thead>
<tr>
<th>Delay to 3 Pellets</th>
<th>6 s/ R</th>
<th>12 s/ R</th>
<th>24 s/ R</th>
<th>0.1 s/R</th>
<th>24 s/R</th>
<th>0.1 s &amp; R</th>
<th>48 s</th>
<th>24 s</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>136F</td>
<td>30/50</td>
<td>40/20</td>
<td>11/24</td>
<td>17/14</td>
<td>25/30</td>
<td>73</td>
<td>43</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td>133F</td>
<td>30/48</td>
<td>39/35</td>
<td>24/76</td>
<td>12/26</td>
<td>66/35</td>
<td>18</td>
<td>52</td>
<td>32</td>
<td>37</td>
</tr>
<tr>
<td>170M</td>
<td>32/48</td>
<td>37/43</td>
<td>12/72</td>
<td>11/40</td>
<td>120/32</td>
<td>38</td>
<td>18</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>171M</td>
<td>30/47</td>
<td>37/31</td>
<td>23/69</td>
<td>11/23</td>
<td>104/36</td>
<td>32</td>
<td>53</td>
<td>23</td>
<td>17</td>
</tr>
<tr>
<td>172M</td>
<td>31/45</td>
<td>36/32</td>
<td>23/14</td>
<td>70/27</td>
<td>24/45</td>
<td>66/23</td>
<td>36</td>
<td>53</td>
<td>22</td>
</tr>
</tbody>
</table>

The order of conditions for each subject is shown in the double outlined rows of the table (from left to right). Each row shows the number of sessions subjects were exposed to each condition and the subsequent contingency reversal. The delay to one pellet remained 0.1 s in each condition.

Second, an individual’s performance could not show any consistent downward or upward trend upon visual inspection of the data from the last 10 sessions. Finally, the mean percentage of self-control choices for the last five sessions could not differ by more than 10% from the mean of the preceding five sessions. Also, note that preference is considered impulsive when the session percentage of large, reinforcer choices dropped below 50%.

**Results**

Figure 2 shows the mean percentage of large reinforcer choices over the last ten sessions of each condition and the last ten sessions of the contingency reversal. The
percentage of large-reinforcer choices was determined by dividing the number of choices for three pellets by the total number of choice trials completed during the session. The dotted horizontal line on each graph references the preference reversal criterion of less than 50 percent self-control choices. All contingency reversals yielded choice percentages almost identical to those before the reversals suggesting that no position bias developed during the course of the experiment. Although it is not indicated in the figure, the percentage of self-control choices was zero during the sessions immediately following a contingency reversal and then recovered suggesting that performance was sensitive to the contingencies associated with responding on each lever. Choice latencies were omitted as the data did not demonstrate consistent trends across trial types. All subjects were originally exposed to a choice between three pellets delayed by 6 s and one pellet after a programmed delay of 0.1 s. Under these conditions, all subjects, except 132F, almost exclusively chose three pellets delayed by 6 s. For the five subjects showing exclusive choices for the large reinforcer, the delay to three pellets was then increased to 12 s and then 24 s during which large reinforcer preference was maintained. The delay associated with the large reinforcer was then decreased to 0.1 s before a delay of 24 s was reintroduced to determine if the gradual change in the delays was responsible for the observed preference for the large, delayed reinforcer. When the 24 s delay was reintroduced, four subjects maintained preference for the large, delayed reinforcer. The choice patterns of subject 170M differed from the other four subjects showing a slight decrease in preference for the large, delayed reinforcer with the first introduction of a delay of 24 s to three pellets and an even larger decrease in self-control choice when the contingencies were reversed (<80% large, delayed reinforcer choices). The delay to three
Figure 2. Each graph shows the percentage of large reinforcer choices for an individual subject across delay conditions. Each bar plot shows the mean and 99% confidence interval based on the last ten sessions of each condition. Means during contingency reversals are indicated by an axis label of R and the large reinforcer delay is the same as that indicated by the bar to the left of that reversal.
pellets was again decreased to 0.1 s and the contingencies reversed prior to the introduction of a 48 s delay. All five subjects (133F, 136F, 170M, 171M, and 172M) showed exclusive large, reinforcer preference during equal 0.1 s delays. Preference reversed for the first time for subject’s 136F, 133F, 170M, 171M, and 172M to the small, immediate reinforcer when the large reinforcer was delayed by 48 s.

Five subjects (136F, 133F, 170M, 171M and 172M) continued to choose the larger, delayed reinforcer on fewer than 20% of the trials when the delay was decreased from 48 s to 24 s. Preference was maintained for the small reinforcer when the contingencies were reversed at a large reinforcer delay of 24 s for subjects 136F, 133F, 171M, 170M, and 172M.

Subject 132F was the only subject to choose one pellet delayed by 0.1 s when the delay to three pellets was 6 s. This subject chose three pellets on almost 100% of the choice trials when the delay was decreased to 3 s. The percentage of large-reinforcer choices remained near 100% or exclusive when the delay to three pellets was then increased to 6 s. This subject, as well as the other five subjects, was sensitive to the amount differences across the two choice alternatives as illustrated by preference for three pellets when both were equally delayed by 0.1 s. Preference reversed to the small reinforcer when the delay to three pellets was increased to 24 s for subject 132F. Reintroduction of a 6 s delay to three pellets resulted in an 80% preference for the large reinforcer that increased to above 90% of large-reinforcer choices when the delay was decreased to 3 s and the contingencies were reversed.
Discussion

The results of this experiment illustrate that when rats are given an opportunity to choose between one pellet that was available almost immediately and three pellets presented following a 6 s delay, most of the subjects will choose the three pellets and will continue to prefer this alternative until that delay is increased to more than 24 s. Some individual differences were observed in that subject 132F chose one pellet available immediately when three pellets were delayed by 6 s. However, most of the subjects continued to choose three pellets on most trials until the delay was increased to 48 s (136F, 133F, 170M, 171M, and 172M). The current findings are inconsistent with those found with pigeons as subjects where preference for the more immediate reinforcer is observed when the delays to the larger reinforcer of 6 s (see review by Logue 1988) and those reported using rats (Eisenberger and Masterson 1987; Eisenberger, Masterson, and Lowman 1982; Evenden and Ryan 1999; Tobin et al. 1993). Tobin et al. (1993) presented rats with a choice between 2 s versus 6 s access to sweetened condensed milk after a delay of 2 s versus 6 s. The current findings are consistent with those reported by van Haaren et al., (1988) who showed that male and female rats chose three pellets delayed by 6 s over one pellet available immediately following a brief history of exposure to both reinforcers equally delayed at 6 s. The current experiment illustrated that such a history was not necessary to obtain self-control preferences in rats.

Choice behavior appeared to depend on the specific sequence of experimental conditions consistent with findings reported with pigeons (Mazur and Logue 1978; Logue and Mazur 1981, Logue et al. 1986). Logue et al. (1986) showed that pigeons would
prefer the delayed but larger reinforcer more often following a history of gradually
decreasing the delay to the small reinforcer of 2 s grain access. The current experiment
illustrated a brief exposure to each increase of the large reinforcer delay would maintain
preference for that reinforcer but also that a brief exposure to a large, reinforcer delay that
could produce a preference reversal modified the influence of shorter delays. For
instance, when the delay to three pellets changed from 6 s to 12 s and finally to 24 s, five
of the subjects continued to prefer three pellets. Those subjects showed that the effects of
gradually increasing the delay was maintained even after a condition of equal, short
delays to both three pellets and one pellet, when the delay increased from 0.1 s to 24 s.
However, all five subjects (136F, 133F, 170M, 171M, and 172M) choose the small
reinforcer when exposed to a delay of 48 s for three pellets when it was preceded with a
0.1 s delay condition. This impulsive choice pattern was maintained when a delay of 24 s
was presented again. This suggests that a subjects delay history can have significant
influences on the self-control choice patterns in the current delay conditions. In other
words, if a delay of 48 s to three pellets were the first large, reinforcer delay presented in
this experiment, all of the subjects would have made impulsive choices for the small,
more immediate reinforcer.
CHAPTER 3  
EXPERIMENT 2  
Introduction

Experiment 1 showed that rats would choose a large delayed reinforcer when presented with a choice between one pellet available almost immediately and three pellets following a delay of 6, 12, or 24 s (five out of the six rats). When the delay to three pellets increased to 48 s, preference reversed and subjects chose three pellets very infrequently if at all. While these results are informative as they confirm and extend previous findings, the procedure produced exclusive preference. The changes in preference from exclusive choices of the large, delayed reinforcer to exclusive choices of the small, immediate reinforcer made it difficult to precisely estimate the delay at which preference began to change. The delay at which preference began to shift from three pellets to one pellet was at a delay between 24 and 48 s, a range of 24 s. The current experiment investigated the point of preference reversal without interpolation by utilizing a fast adjusting-delay procedure, a modification of the procedure proposed by Richards, Mitchell, de Wit, and Seiden (1997).

Richards et al. (1997) presented rats with a choice between a standard alternative of 100 µl of delayed water delivery and an adjusting amount of immediate water delivery. The amount of water immediately delivered changed by 10% after each choice trial depending on the subject’s performance. The amount of water increased following a choice for the standard alternative and decreased following a choice for the adjusting
alternative. Different standard delays were presented each day of the week (0, 2, 4, 8 or 16 s) over the course of a five-week cycle of standard delay presentation. Each session began with forced exposure to both choice alternatives followed by choice trials. Forced exposure trials were only presented following two consecutive choices for one alternative and it was forced exposure to the non-chosen alternative. Sessions included sixty choice trials and indifference points were determined during the final thirty choice trials within a session.

The rapid adjusting procedure proposed by Richards et al. (1997) includes several procedural differences from that used by Mazur (1987; 1988). First, the adjusting alternative changed following each choice trial instead of following the completion of a block of several trials. Second, which alternative adjusted differed across the two procedures. In Mazur’s procedure the delay for the large, delayed reinforcer changed and the amount of small, immediate reinforcement changed in the Richards et al. (1997) procedure. Third, the adjusting parameter changed by a percentage of the current amount of water instead of by a fixed adjustment of 1 s to the delay. Finally, Richards et al. (1997) presented a new standard alternative each day of the week such that the development of indifference was assessed for many standard alternatives during the same condition of the experiment.

Regardless of these procedural differences, the two procedures have been used to produce comparable findings (Ho et al. 1997; Mazur 1987; 1988 Mazur et al. 1987; Mobini et al. 2000; Tobin et al. 1993; Wade et al. 2000; Wogar et al. 1992; 1993). The discount functions, the mean adjusting delay to the large reinforcer as a function of the standard reinforcer, produced by the pigeons in Mazur’s (1987) study showed that as the
standard delay to a small reinforcer increased the adjusting delay to the large reinforcer also increased. The discount functions produced by rats in Richards et al. (1997) adjusting amount procedure produced a similar function in that as the delay to the larger reinforcer increased the adjusted amount of immediate (water) reinforcement at indifference decreased. The results from both experiments can be summarized as showing that as some delay to reinforcer receipt is added, the value of that reinforcer or preference for that reinforcer is decreased. The hyperbolic equation (Mazur, 1987) has reliably quantified this relationship between reinforcer value and reinforcement parameters of amount and delay.

The current experiment was designed to examine indifference points of rats using a modified version of Richard’s et al. (1997) rapid adjusting procedure; the delay associated with the large reinforcer was manipulated instead of the amount of immediate reinforcement. The specific goals of this experiment were threefold: First, to examine the utility of using this modified version of the Richards et al. (1997) rapid adjusting procedure to produce indifference points within an individual session; Second, to examine the utility of using this modified rapid adjusting procedure to produce data consistent with findings reported using the standard adjusting procedure; Third, to determine if predictions made based on the observed indifference points from Experiment II are consistent with the findings from Experiment I.

Methods

Subjects
The subjects were three female and four male experimentally naïve Long Evans rats. At the beginning of the experiment, the mean body weight for the female subjects was 324 grams and the mean body weight for male subjects was 387 grams. The subjects
were individually housed with continuous availability of water but restricted access to food. Female subjects received 12 grams and males received 15 grams of food each day, presented immediately following the experimental sessions or at approximately that time of day on weekend days when no experimental session was conducted. This daily feeding regimen allowed approximately 22 hours of food deprivation at the start of each experimental session. A reversed light cycle consisted of lights off at 7:00 a.m. and on at 7:00 p.m. with all experimental sessions conducted during the dark cycle between 11:00 a.m. and 6:00 p.m. on Sunday through Friday.

**Apparatus**

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

**Procedures**

**Preliminary training.** Same as in Experiment 1.

**General experimental procedures.** A session consisted of two trial types-forced exposure trials and choice trials. A session started with forced exposure to both choice options but the order of their presentation was randomly determined at the beginning of each session. The remaining forced exposure trials were presented based on a subject’s making two consecutive choices for one alternative producing a forced exposure trial for the non-selected alternative. For instance, if a subject chose the adjusting alternative on trials 10 and 11 then the following trial (trial 12) would be a forced exposure trial for the standard alternative. This arrangement ensured exposure to both alternatives during the session but on some undetermined number of trials.

A trial was initiated with the illumination of the houselight and stimulus lights above the lever(s). One set of stimulus lights was illuminated continuously and the other set of stimulus lights blinked (on/off cycle of 0.75/0.1 s). Completion of three
consecutive responses (fixed ratio or FR 3) on the lever associated with blinking stimulus lights extinguished all stimulus lights and initiated a delay to pellet presentation that was signaled by a blinking houselight. Completion of the FR 3 on the lever associated with continuous stimulus lights extinguished all stimulus lights and initiated a delay to pellet presentation signaled by continuous illumination of the houselight. The pellet receptacle was illuminated for 2-s during food delivery. A pellet was always presented simultaneously with illumination of the receptacle. For the large reinforcer, two additional pellets were delivered at 1 s intervals. Completion of the reinforcer delivery initiated the intertrial interval (ITI), during which all chamber lights were extinguished. Trials were scheduled to start 30 s from a choice response if at least 10 s had elapsed between food presentation and the scheduled start of the next trial. If the 10 s minimum requirement was not met, the next trial started after another 30 s had elapsed.

The standard alternative of one pellet was presented following a fixed delay and the adjusting alternative was three pellets presented following an adjusting delay. The standard delay to one pellet was 0.1, 2, or 8 s for three female and two male subjects in this experiment (1125F, 1126F, 1127F, 1131M, and 1132M). The standard delay was 0.1, 4, or 16 s for two additional male subjects in this experiment (1134M and 1136M). Each standard delay was presented twice a week. The adjusting delay was either 6 s (Low) or 20 s (High) at the start of an experimental session. When the possible standard delays and either a high or low start value of the adjusting delay are combined, subjects were exposed to a five-week regimen of parameter presentations that are indicated in Table 2. This regimen was recycled for the duration of the experiment. The adjusting delay changed by 10% or 1 s following each choice trial. If 10% of the adjusting delay
was less than 1 s, then the delay on the following trial changed by 1 s but otherwise the adjusting delay changed by 10%. Although the adjusting delay could never decrease below the standard delay, no upper limit was placed on the adjusting alternative. The number of trials that could be completed in a session was the only upper limit on the adjusting delay.

Experimental conditions. There were three experimental conditions in Experiment 2 and subjects were exposed to the conditions in numerical order. In the first two conditions of the experiment, one of three different standard delays was presented each day of the week. As indicated in Table 2, each delay was presented twice a week, once with a high (20 s) starting value and once with a low starting value (6 s).

Stability criteria. Subjects were exposed to the five-week regimens shown in Table 2 at least three times in Conditions 1 and 2 and at least once in Condition 3. Stability was defined in terms of within session changes in the adjusting delay (within session criteria) and by the number of sessions including stable performance during a five-week regimen (across session criteria). The main dependent measure across all three experimental conditions was the adjusting delay in seconds. Within-session stability was assessed over a block of ten choice trials and was considered stable when several criteria were met. First, no consistent upward or downward trend in the adjusting delay was observed during the ten trial block. Second, the mean adjusting delay for the last five choice trials of that block could not differ from the preceding five-trial mean by more than 10%. Stability was assessed during choice trials after completion of trial 30. The first ten-trial block to be assessed for stability was across trials 31 through 40. If the within session stability criteria were not met in that ten–trial block, stability was then
assessed following the completion of five more choice trials, i.e., on trials 36 through 45. This recursive process of stability assessment was used for the remaining trials of the session. The across session criteria included the following requirements: A minimum of three exposures to the entire five-week regimen; Completion of all 60 choice trials in 24 out of 30 sessions included in a five-week cycle (only in Condition 1); Meeting the within session stability criteria in a minimum of 80 percent of the sessions in a single five-week series, 24 out of 30 (Conditions 2 and 3).

**Condition 1.** Sessions lasted for a total of 120 minutes or until 60 choice trials were completed. This condition lasted for a total of 20 weeks or four times through the five-week series shown in Table 2. Performance was considered stable and the condition terminated when analysis of within-session data during a five-week period included the development of stable indifference points (defined as within-session criteria) during 80% of the sessions, i.e., 24 out of 30 sessions. Tables 4 and 5 indicate the mean adjusting delay and the trials over which stability was met for individual sessions in this condition.

**Condition 2.** This condition lasted for another twenty weeks of four exposures to the same five-week regimen as in Condition 1. This condition differed from Condition 1 in that sessions terminated as soon as stability was met within each session. As previously described, within-session stability was assessed over a block of ten choice trials beginning after completion of choice trial 30. If within session stability was met, the session ended. If performance did not meet the within session stability criteria, another five choice trials were completed and stability assessed over the last ten trials.
This change was included to determine if stable indifference points could be obtained during short sessions. If within-session stability was not reached, the session terminated following 120 minutes or completion of 60 choice trials as in Condition 1.

Table 2. The order of standard delay presentation in experimental Conditions 1 and 2.

<table>
<thead>
<tr>
<th>Day</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunday</td>
<td>8 s (Low)</td>
<td>0.1 s (Low)</td>
<td>0.1 s (Low)</td>
<td>2 s (Low)</td>
<td>8 s (High)</td>
</tr>
<tr>
<td>Monday</td>
<td>0.1 s (Low)</td>
<td>2 s (Low)</td>
<td>8 s (High)</td>
<td>0.1 s (High)</td>
<td>2 s (Low)</td>
</tr>
<tr>
<td>Tuesday</td>
<td>2 s (High)</td>
<td>8 s (High)</td>
<td>0.1 s (High)</td>
<td>8 s (Low)</td>
<td>2 s (High)</td>
</tr>
<tr>
<td>Wednesday</td>
<td>0.1 s (High)</td>
<td>8 s (Low)</td>
<td>2 s (Low)</td>
<td>2 s (High)</td>
<td>0.1 s (Low)</td>
</tr>
<tr>
<td>Thursday</td>
<td>8 s (High)</td>
<td>2 s (High)</td>
<td>8 s (Low)</td>
<td>0.1 s (Low)</td>
<td>0.1 s (High)</td>
</tr>
<tr>
<td>Friday</td>
<td>2 s (Low)</td>
<td>0.1 s (High)</td>
<td>2 s (High)</td>
<td>8 s (High)</td>
<td>8 s (Low)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunday</td>
<td>16 s (Low)</td>
<td>0.1 s (Low)</td>
<td>0.1 s (Low)</td>
<td>4 s (Low)</td>
<td>16 s (High)</td>
</tr>
<tr>
<td>Monday</td>
<td>0.1 s (Low)</td>
<td>4 s (Low)</td>
<td>16 s (High)</td>
<td>0.1 s (High)</td>
<td>4 s (Low)</td>
</tr>
<tr>
<td>Tuesday</td>
<td>4 s (High)</td>
<td>16 s (High)</td>
<td>0.1 s (High)</td>
<td>16 s (Low)</td>
<td>4 s (High)</td>
</tr>
<tr>
<td>Wednesday</td>
<td>0.1 s (High)</td>
<td>16 s (Low)</td>
<td>4 s (Low)</td>
<td>4 s (High)</td>
<td>0.1 s (Low)</td>
</tr>
<tr>
<td>Thursday</td>
<td>16 s (High)</td>
<td>4 s (High)</td>
<td>16 s (Low)</td>
<td>0.1 s (Low)</td>
<td>0.1 s (High)</td>
</tr>
<tr>
<td>Friday</td>
<td>4 s (Low)</td>
<td>0.1 s (High)</td>
<td>4 s (High)</td>
<td>16 s (High)</td>
<td>16 s (Low)</td>
</tr>
</tbody>
</table>

The top portion of the table shows the weekly regimen for subject’s 1125F, 1126F, 1127F, 1131M, and 1132M in experimental Conditions 1 and 2. The lower portion of the table shows the weekly regimen for subject’s 1134M and 1136M in experimental Conditions 1 and 2. A high in parenthesis are sessions when the adjusting delay was 20 s at the start of the session. A low in parenthesis are sessions when the adjusting delay was 6 s at the start of the session. This five-week regimen was recycled a minimum of three times.
**Condition 3.** The final condition of the experiment included an assessment of indifference points when the same standard delay was presented across all sessions for an entire five-week period. Table 3 shows the order of standard delay presentations for all subjects in this condition of Experiment 2. This condition was designed to investigate if different indifference points would be observed when the standard delay remained fixed instead of changing each day of the week as in Conditions 1 and 2. This condition only included six of the original seven subjects as one subject died during Condition 3 and those data were excluded.

Table 3. The order of standard delay presentation during experimental Condition 3.

<table>
<thead>
<tr>
<th></th>
<th>1126F</th>
<th>1127F</th>
<th>1131M</th>
<th>1132M</th>
<th>1134M</th>
<th>1136M</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>0.1 s</td>
<td>8 s</td>
<td>8 s</td>
<td>0.1 s</td>
<td>0.1 s</td>
<td>16 s</td>
</tr>
<tr>
<td>Second</td>
<td>2 s</td>
<td>2 s</td>
<td>2 s</td>
<td>2 s</td>
<td>2 s</td>
<td>2 s</td>
</tr>
<tr>
<td>Third</td>
<td>8 s</td>
<td>0.1 s</td>
<td>0.1 s</td>
<td>8 s</td>
<td>4 s</td>
<td>4 s</td>
</tr>
<tr>
<td>Fourth</td>
<td></td>
<td></td>
<td></td>
<td>16 s</td>
<td>0.1 s</td>
<td></td>
</tr>
</tbody>
</table>

Each standard delay was presented for a single five-week period with the same order of high and low start values of the adjusting delays as shown in Table 2.

**Results**

**Condition 1.** Figures 3 through 9 show changes in the adjusting delay across trials during the final five weeks of the first experimental Condition. Each figure includes data for one subject. The vertical axis of each plot shows the adjusting delay in seconds ranging from 0 to 120 s or 0 to 70 s. Each graph includes two sessions with the same standard delay, indicated by the same symbols, but different starting values for the
adjusting delay of either 6 s (open symbol) or 20 s (filled symbol). The dotted vertical line in each graph references trial thirty after which within-session stability was determined. The legend to the right of each graph indicates the order of standard delay presentation for that week starting from Sunday through Friday. Table 4 shows the mean adjusting delay when stability was reached during the session for 1125F, 1126F, and 1127F. Table 5 shows the mean adjusting delay when stability was reached during the session for subjects 1131M, 1132M, 1134M, and 1136M. Both tables show the mean adjusting delay across the first ten-trial block after trial 30 that met the within session stability criteria and an asterisk indicates that those criteria were not met within that session. The within-session stability criteria were not met during some sessions as the subjects completed fewer than 40 choice trials during the session as noted in parenthesis.

Subject 1125F developed stable indifference points during 27 out of 30 sessions in the final five-weeks of the first experimental condition shown in Figure 3. Table 4 has asterisks to indicate the three sessions during which stability was not reached within the session. Figure 3 shows that some sessions included the development of a stable adjusting delay over a ten trial block that was then followed by an unstable adjusting delay where subject 1125F repeatedly chose one alternative. For instance, in week one, the adjusting delay fulfilled the within session stability criteria across trials 41 through 50 with a mean adjusting delay of 47 s that was followed by persistent choices for the standard alternative of one pellet delayed by 8 s producing a consistent decrease in the adjusting delay and unstable performance. As indicated in Table 4, the start value of the adjusting delay sometimes influenced the mean adjusting delay at indifference. Sometimes the indifference point was higher when the adjusting delay started low rather
than high. Both Table 4 and Figure 3 show that the range of mean adjusting delays at indifference overlapped across standard delays, i.e., 4 s to 33 s, 7 s to 14 s, and 12 s to 47 s with standard delays of 0.1 s, 2 s, and 8, respectively. Regardless of this similarity across standard delays, stable indifference was observed much earlier in the session when the standard delay was 0.1 s than when it was either 2 s or 8 s.

Figure 4 shows data for subject 1126F during the final five-week period of the first condition. All sessions included the establishment of indifference points (stable adjusting delays) within the session. The development of indifference was followed by two different within-session patterns. During some sessions, stable indifference was followed by unstable performance during the final trials of the session. This pattern is demonstrated when the standard delay was 8 s in the second week. The adjusting delay was increased from 6 s to 68 s over trials 1 to 45 and performance met stability criteria during trials 31 through 40. This was followed by a brief increase and then a consistent decrease across the remaining trials of that session with the session terminating on unstable within-session performance. A second within-session pattern that was observed included the development of a stable adjusting delay at two different times during the same session. This pattern is shown in the fifth week when the standard delay was 8 s. The adjusting delay increased from 20 to 115 s over trials 1 through 30 and then decreased to approximately 70 s during trials 30 through 45, meeting the stability criterion, and then decreased to a stable mean adjusting delay of 48 s during trials 51 through 60. Two different stable indifference points were obtained during that single session, 70 s and 48 s. This within-session pattern was seen with the high standard delay than the two shorter standard delays. Table 5 shows that the mean adjusting delays
ranged from 12 s to 38 s, 3 s to 45 s, and 21 s to 73 s when the standard delays were 0.1, 2, or 8 s, respectively. The range of indifference points was more similar when the standard delay was 0.1 s or 2 s but extended up through larger delays when the standard delay was 8 s.

The data for subject 1127F in Figure 5 show the development of stable indifference within 28 out of 30 sessions during the final five-weeks of Condition 1. Stability was not met during these two sessions because less than 40 choice trials were completed during those two sessions. Several sessions included the development of stable indifference at some point in the session followed by a consistent decrease in the adjusting delay. This is seen in the fifth week during trials 31 to 40 when the standard delay was 2 s and the mean adjusting delay for three pellets was 61 s. Although performance was stable at trial 40, subject 1127F consistently chose the standard alternative for the remainder of the session producing a steady decrease in the adjusting delay. Data from the second week shows a similar pattern of stability followed by a decline in the adjusting delay during both sessions when the standard delay was 8 s. Figure 5 also shows that, although some overlap was observed, the adjusting delay was consistently higher with the higher standard delays. This is supported by the range of indifference points observed which were 1 s to 11 s, 2 s to 14 s, and 11 s to 38 s with standard delays of 0.1 s, 2 s, or 8 s, respectively.

Figure 6 shows that subject 1131M developed a stable indifference point in 28 out of 30 sessions during the final five-week period of the first condition. Subject 1131M’s general pattern within a session was to increase or decrease the adjusting delay until the subject was indifferent between the two alternatives and then to alternate between the two
Table 4. The Mean Adjusting Delay at Indifference in Condition 1.

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1125F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>14 (41-50)</td>
<td>6 (31-40)</td>
<td>*</td>
<td>4 (31-40)</td>
<td>5 (31-40)</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>5 (31-40)</td>
<td>33 (41-50)</td>
<td>33 (41-50)</td>
<td>7 (31-40)</td>
<td>6 (31-40)</td>
</tr>
<tr>
<td>2 s (Low)</td>
<td>9 (41-50)</td>
<td>13 (36-45)</td>
<td>12 (36-45)</td>
<td>13 (36-45)</td>
<td>14 (46-55)</td>
</tr>
<tr>
<td>2 s (High)</td>
<td>13 (36-45)</td>
<td>*</td>
<td>7 (31-40)</td>
<td>11 (31-40)</td>
<td>10 (41-50)</td>
</tr>
<tr>
<td>8 s (Low)</td>
<td>47 (41-50)</td>
<td>34 (46-55)</td>
<td>42 (51-60)</td>
<td>16 (41-50)</td>
<td>19 (36-45)</td>
</tr>
<tr>
<td>8 s (High)</td>
<td>12 (46-55)</td>
<td>16 (36-45)</td>
<td>*</td>
<td>24 (31-40)</td>
<td>23 (31-40)</td>
</tr>
<tr>
<td>1126F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>21 (31-40)</td>
<td>18 (51-60)</td>
<td>12 (36-45)</td>
<td>21 (31-40)</td>
<td>38 (36-45)</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>27 (36-45)</td>
<td>38 (41-50)</td>
<td>38 (41-50)</td>
<td>29 (36-45)</td>
<td>25 (41-50)</td>
</tr>
<tr>
<td>2 s (Low)</td>
<td>23 (51-60)</td>
<td>45 (31-40)</td>
<td>42 (46-55)</td>
<td>23 (31-40)</td>
<td>3 (36-45)</td>
</tr>
<tr>
<td>2 s (High)</td>
<td>35 (41-50)</td>
<td>23 (36-45)</td>
<td>31 (36-45)</td>
<td>41 (31-40)</td>
<td>35 (46-55)</td>
</tr>
<tr>
<td>8 s (Low)</td>
<td>34 (41-50)</td>
<td>68 (31-40)</td>
<td>46 (46-55)</td>
<td>34 (31-40)</td>
<td>39 (36-45)</td>
</tr>
<tr>
<td>8 s (High)</td>
<td>53 (31-40)</td>
<td>73 (41-50)</td>
<td>21 (46-55)</td>
<td>55 (31-40)</td>
<td>70 (36-45)</td>
</tr>
<tr>
<td>1127F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>1 (36-45)</td>
<td>1 (31-40)</td>
<td>1 (31-40)</td>
<td>1 (31-40)</td>
<td>6 (31-40)</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>1 (31-40)</td>
<td>1 (31-40)</td>
<td>11 (31-40)</td>
<td>* (Not finish)</td>
<td>1 (31-40)</td>
</tr>
<tr>
<td>2 s (Low)</td>
<td>7 (31-40)</td>
<td>4 (31-40)</td>
<td>11 (31-40)</td>
<td>4 (31-40)</td>
<td>61 (31-40)</td>
</tr>
<tr>
<td>2 s (High)</td>
<td>2 (31-40)</td>
<td>6 (31-40)</td>
<td>4 (31-40)</td>
<td>5 (31-40)</td>
<td>4 (31-40)</td>
</tr>
<tr>
<td>8 s (Low)</td>
<td>15 (31-40)</td>
<td>39 (46-55)</td>
<td>14 (36-45)</td>
<td>12 (36-45)</td>
<td>11 (31-40)</td>
</tr>
<tr>
<td>8 s (High)</td>
<td>37 (31-40)</td>
<td>47 (41-50)</td>
<td>38 (36-45)</td>
<td>* (Not finish)</td>
<td>12 (31-40)</td>
</tr>
</tbody>
</table>

Mean adjusting delay, to the nearest second, when stability was reached within a session for subject’s 1125F, 1126F, and 1127F. The choice trials comprising this mean are shown in parentheses.

alternatives for the remainder of the session. Only a few sessions terminated with a decreasing (when standard delay was 8 s in the second week) or increasing (when the standard delay was 8 s in week 1) trend in the adjusting delay. Table 5 indicates that the adjusting delays at indifference were very similar across standard delays with all of the mean adjusting delays ranging from 6 s (only one session) to 55 s while the central tendency ranging from 25 s to 42 s across all standard delays. Nonetheless, the highest indifference points were correlated with the highest standard delays.
Data for subject 1132M are shown in Figure 7. The data from the final five-week period for this subject included three sessions during which the subject continually preferred the large reinforcer (adjusting alternative), which resulted in steady increases of the adjusting delay until the session terminated. Two of these sessions occurred when the standard delay was 0.1 s (terminal adjusting delay of 142 s and 200 s) and one when the standard delay was 2 s with a terminal adjusting delay of 170 s. One session in the fifth week did not include the development of stable indifference due to consistent preference for the standard alternative. The remaining sessions included less exclusive responding and 26 out of 30 sessions included the development of stable indifference at some point during the session. The range of stable indifference points were 11 s to 28 s, 12 s to 36 s, and 16 s to 46 s when the standard delay was 0.1 s, 2 s, or 8 s, respectively.

Figure 8 and 9 include data for subjects 1134M and 1136M, respectively. Unlike the other five subjects in this experiment, these two subjects were exposed to standard delays of 0.1 s, 4 s, and 16 s. Figure 8 shows that the within-session performance of subject 1134M became stable or indifferent during 25 out of 30 of the final sessions in Condition 1. Performance during one session did not meet the stability criteria as less than 40 choice trials were completed during the session. Although many sessions included the development of a stable adjusting delay, the performance did not always remain stable for the remainder of the sessions. Subject 1134M consistently chose the small reinforcer following either a 4 s or a 16 s standard delay during the final trials of sessions in the first and second weeks producing consistent decreases in the adjusting delay. The mean adjusting delays at stability were closely approximated across sessions containing the same standard delay. For instance, the mean adjusting delay during the
Table 5. The Mean Adjusting Delay at Indifference Condition 1.

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1131M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>21 (36-45)</td>
<td>6 (31-40)</td>
<td>32 (31-40)</td>
<td>34 (41-50)</td>
<td>23 (36-45)</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>42 (31-40)</td>
<td>38 (36-45)</td>
<td>*</td>
<td>24 (36-45)</td>
<td>25 (31-40)</td>
</tr>
<tr>
<td>2 s (Low)</td>
<td>38 (31-40)</td>
<td>24 (41-50)</td>
<td>34 (36-45)</td>
<td>36 (46-55)</td>
<td>43 (36-45)</td>
</tr>
<tr>
<td>2 s (High)</td>
<td>16 (46-55)</td>
<td>*</td>
<td>48 (31-40)</td>
<td>48 (31-40)</td>
<td>33 (31-40)</td>
</tr>
<tr>
<td>8 s (Low)</td>
<td>26 (41-50)</td>
<td>31 (41-50)</td>
<td>41 (31-40)</td>
<td>38 (41-50)</td>
<td>37 (51-60)</td>
</tr>
<tr>
<td>8 s (High)</td>
<td>24 (31-40)</td>
<td>47 (36-45)</td>
<td>41 (31-40)</td>
<td>55 (31-40)</td>
<td>42 (31-40)</td>
</tr>
<tr>
<td>1132M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>*</td>
<td>12 (46-55)</td>
<td>*</td>
<td>28 (46-55)</td>
<td>19 (31-40)</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>15 (36-45)</td>
<td>11 (36-45)</td>
<td>13 (36-45)</td>
<td>15 (36-45)</td>
<td>12 (41-50)</td>
</tr>
<tr>
<td>2 s (Low)</td>
<td>25 (36-45)</td>
<td>12 (36-45)</td>
<td>*</td>
<td>30 (46-55)</td>
<td>14 (51-60)</td>
</tr>
<tr>
<td>2 s (High)</td>
<td>13 (31-40)</td>
<td>23 (31-40)</td>
<td>19 (31-40)</td>
<td>36 (46-55)</td>
<td>12 (31-40)</td>
</tr>
<tr>
<td>8 s (Low)</td>
<td>16 (31-40)</td>
<td>16 (41-50)</td>
<td>46 (46-55)</td>
<td>20 (31-40)</td>
<td>32 (36-45)</td>
</tr>
<tr>
<td>8 s (High)</td>
<td>21 (36-45)</td>
<td>23 (36-45)</td>
<td>18 (46-55)</td>
<td>32 (41-50)</td>
<td>*</td>
</tr>
<tr>
<td>1134F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>21 (31-40)</td>
<td>* (Not finish)</td>
<td>29 (36-45)</td>
<td>10 (41-50)</td>
<td>20 (36-45)</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>12 (36-45)</td>
<td>25 (36-45)</td>
<td>31 (31-40)</td>
<td>30 (31-40)</td>
<td>24 (31-40)</td>
</tr>
<tr>
<td>4 s (Low)</td>
<td>58 (31-40)</td>
<td>48 (36-45)</td>
<td>36 (46-55)</td>
<td>52 (31-40)</td>
<td>26 (51-60)</td>
</tr>
<tr>
<td>4 s (High)</td>
<td>25 (36-45)</td>
<td>39 (31-40)</td>
<td>38 (51-60)</td>
<td>37 (31-40)</td>
<td>*</td>
</tr>
<tr>
<td>16 s (Low)</td>
<td>*</td>
<td>63 (31-40)</td>
<td>52 (31-40)</td>
<td>*</td>
<td>52 (31-40)</td>
</tr>
<tr>
<td>16 s (High)</td>
<td>40 (41-50)</td>
<td>40 (31-40)</td>
<td>55 (31-40)</td>
<td>*</td>
<td>42 (31-40)</td>
</tr>
<tr>
<td>1136F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>24 (31-40)</td>
<td>27 (31-40)</td>
<td>35 (31-40)</td>
<td>10 (41-50)</td>
<td>20 (36-45)</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>30 (31-40)</td>
<td>30 (31-40)</td>
<td>41 (36-45)</td>
<td>30 (31-40)</td>
<td>24 (31-40)</td>
</tr>
<tr>
<td>4 s (Low)</td>
<td>36 (31-40)</td>
<td>29 (31-40)</td>
<td>51 (36-45)</td>
<td>52 (31-40)</td>
<td>26 (51-60)</td>
</tr>
<tr>
<td>4 s (High)</td>
<td>32 (31-40)</td>
<td>*</td>
<td>* (Not finish)</td>
<td>37 (41-50)</td>
<td>*</td>
</tr>
<tr>
<td>16 s (Low)</td>
<td>25 (41-50)</td>
<td>*</td>
<td>52 (36-45)</td>
<td>*</td>
<td>52 (31-40)</td>
</tr>
<tr>
<td>16 s (High)</td>
<td>51 (31-40)</td>
<td>50 (31-40)</td>
<td>60 (31-40)</td>
<td>*</td>
<td>42 (31-40)</td>
</tr>
</tbody>
</table>

Mean adjusting delay, to the nearest second, when stability was reached within a session for subject 1131M, 1132M, 1134M, and 1136M during Condition 1. The choice trials comprising this mean are shown in parentheses.

fifth week was 52 s and 42 s when the standard delay was 16 s but 20 s and 24 s when the standard delay was 0.1 s. Indifference points increased with increased standard delays;
they ranged from 10 s to 31 s, 25 s to 58 s, and 40 s to 63 s with standard delays of 0.1 s, 4 s, and 16 s.

The performance of subject 1136M showed the development of stable indifference within the session for 24 out of 30 of the sessions included in Figure 9. Two of the sessions that did not include the development of stable performance, included persistent responding for the adjusting alternative or large reinforcer (three pellets) when the standard delay to one pellet was 4 s or 16 s and both of these performances were observed during the 5th week. The mean adjusting delay was very similar across standard delays with ranges of 10 s to 41 s, 29 s to 53 s, and 25 s to 52 s with standard delays of 0.1 s, 4 s, and 16 s, respectively. Similar indifference points were observed when the standard delay was either 4 s or 16 s but the lowest indifference points were shown with the 0.1 s standard delay.

Several general choice patterns emerge from the data in Figures 3 through 9. All of the subjects were beginning to show stable adjusting delays at some point during the final portion of individual sessions, i.e., trials 30 through 60, during at least 80% of the 30 sessions from the final 5 weeks of Condition 1. Secondly, subjects completed almost all 60 possible choice trials during the 2-hour experimental session. Although the adjusting delay often became stable during the session and then unstable during the final trials of the session. Fourth, the indifference point tended to be higher with higher standard delays although many indifference points were nominally similar across standard delays especially during sessions including the standard delays of 0.1, 2, or 4 s. Finally, sessions when the standard delay was highest, 8 or 16 s, included more within-
session variability which is mostly likely due to how the adjusting delay was programmed to change.

Figure 10 is a summary plot of the data in Condition 1. Each graph shows the mean adjusting delay at indifference when the within session stability criteria were met as indicated in Tables 4 and 5. Each mean adjusting delays was determined across the final 10 trials of the five individual sessions shown in Figures 3 through 9. The filled symbols indicate the means when the adjusting delay was 20 s at the beginning of each session while the open symbols indicate sessions when the adjusting delay was 6 s. Indifference points were not consistently modified by the adjusting delay at the beginning of the session but instead the indifference points were similar whether the adjusting delay was 20 s or 6 s at the beginning of the session. The summary plot demonstrates some across session variability in the indifference point in sessions with the same standard delay but an increasing indifference point with increased standard delays to one pellet.

**Condition 2.** Figures 11 through 17 show choice performance during the final five-week period of the second experimental condition when session termination was based on meeting the within-session stability criteria. Each figure includes five graphs corresponding to the final five-weeks of this condition. Each graph includes within-session data for six sessions completed during a week. A legend is provided to the right of each graph indicating the order of standard delay presentations from Sunday through Friday of that week. A dotted reference line is included at trial 30 after which within-session stability was determined (vertical line on each graph). Table 6 shows the mean adjusted delay during the final 10 choice trials of each session for subject’s 1125F.
Figure 3. Condition 1 for subject 1125F. This figure shows within-session data during the final five weeks of the first condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols).
Figure 4. Condition 1 for subject 1126F. This figure shows within-session data during the final five weeks of the first condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols).
Adjusting delay (sec)

Trials Within a Session

Week 1

- 8 s (Low)
- 0.1 s (Low)
- 2 s (High)
- 0.1 s (High)
- 8 s (High)
- 2 s (Low)

Week 2

- 0.1 s (Low)
- 2 s (Low)
- 8 s (High)
- 8 s (Low)
- 2 s (High)
- 0.1 s (High)

Week 3

- 0.1 s (Low)
- 8 s (High)
- 0.1 s (High)
- 2 s (Low)
- 8 s (Low)
- 2 s (High)

Week 4

- 2 s (Low)
- 0.1 s (High)
- 8 s (Low)
- 8 s (High)
- 2 s (High)
- 0.1 s (Low)

Week 5

- 8 s (High)
- 2 s (Low)
- 2 s (High)
- 0.1 s (Low)
- 0.1 s (High)
- 8 s (Low)
Figure 5. Condition 1 for subject 1127F. This figure shows within-session data during the final five weeks of the first condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols).
Figure 6. Condition 1 for subject 1131M. This figure shows within-session data during the final five weeks of the first condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols).
Figure 7. Condition 1 for subject 1132M. This figure shows within-session data during the final five weeks of the first condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols).
Figure 8. Condition 1 for subject 1134M. This figure shows within-session data during the final five weeks of the first condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols).
Figure 9. Condition 1 for subject 1136M. This figure shows within-session data during the final five weeks of the first condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols).
Figure 10. Condition 1 Summary Plot. This figure shows mean adjusting delay and 95% confidence intervals of the data in the second experimental condition over the last ten trials of the session as a function of the standard delay. The open symbols show data from sessions during which the adjusting delay started at 6 s and the filled symbols plot data from when the adjusting delay started at 20 s.
1126F, and 1127F and Table 7 shows the mean adjusting delay during the final 10 choice trials of each session for subjects, 1131M, 1132M, 1134M, and 1136M.

Figure 11 shows data for Subject 1125F which included the development of stable indifference and early termination of 29 out of 30 experimental sessions during the final five week period of Condition 2. Indifference points were highly correlated with the standard delay with higher standard delays resulting in higher adjusting delays. For instance, the mean adjusting delays from the fourth week were 3 s, 14 s, and 56 s when the standard delays were 0.1 s, 2 s, or 8 s, respectively and the start value of the adjusting delay was 6 s. Furthermore, the mean adjusting delays were 3 s, 12 s, and 40 s when the standard delays were 0.1 s, 2 s, and 8 s, respectively and the start value of the adjusting delay was 20 s. The mean adjusting delay tended to be more similar when the standard delay was either 0.1 or 2 s than when the standard delay was 8 s during all five weeks shown in Figure 11. The mean adjusting delays were less than 10 s in 3 out of the four indifference points in that second week when the standard delay was 0.1 s or 2 s while the indifference points were much higher (43 s and 118 s) when the standard delay was 8 s. The mean adjusting delays observed with a given standard delay during the fourth week were almost identical regardless of the start value of the adjusting delay.

The performance of subject 1126F met the within session stability criteria, shown in Figure 12, in 28 out of 30 of the sessions during the final five-weeks of Condition 2. Early session termination was typically within the first fifty trials with most sessions terminating after trial 45. Stability was not reached within the session for two sessions when the standard delay was 8 s and the adjusting alternative started at 20 s. Table 6 shows the indifference points ranged from 6 s to 55 s, 2 s to 54 s, and 19 to 95 s with
standard delays of 0.1 s, 2 s, and 8 s. Indifference points were virtually indistinguishable when the standard delay was 0.1 s or 2 s.

Subject 1127F developed stable indifference within the session for 27 out of 30 of the sessions. Overall, the mean adjusting delay at indifference was consistently lower than observed for the other subjects. The adjusting delay at indifference was consistently 2 seconds when the standard delay was 0.1 s, with one exception, while the adjusting delay only ranged from 8 s to 20 s when the standard delay was 8 s. Although there were some similarities in the indifference points across standard delays, the indifference points tended to increase as the standard delay increased. For instance, the indifference points during the fifth week were 2 s and 2 s, 10 s and 6 s, or 10 s and 20 s when the standard delays were 0.1 s, 2 s, or 8 s and the adjusting delay started at 6 s and 20 s, respectively. Figure 13 shows that sessions typically terminated following completion of only 40 choice trials, as performance was stable. As a result, sessions only lasted approximately twenty-five to thirty minutes.

Subject 1131M’s data are shown in Figure 14 and this subject showed stable indifference points during 29 of 30 of the final sessions of the second experimental condition. The only session that did not include stable performance was because fewer than 40 choice trials being completed during that session. Again, the mean adjusting delays tended to increase with increasing standard delays for this subject as seen with previous subjects. The performance of the first week shows indifference points of 2 s or 12 s, 13 s or 23 s, and 61 s or 33 s for standard delays of 0.1 s, 2 s, or 8 s and low or high adjusting delays at the start of the session, respectively. Similarly, the performance of the
second week shows indifference points of 2 s or 21 s, 11 s, and 26 s or 29 s for standard delays of 0.1 s, 2 s, or 8 s, and low or high beginning adjusting delays, respectively.

Table 6. The Mean Adjusting Delay at Indifference in Condition 2.

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1125F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 s (Low)</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>2</td>
<td>4</td>
<td>42</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2 s (Low)</td>
<td>6</td>
<td>27</td>
<td>13</td>
<td>14</td>
<td>45</td>
</tr>
<tr>
<td>2 s (High)</td>
<td>21</td>
<td>2</td>
<td>16</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>8 s (Low)</td>
<td>80</td>
<td>43</td>
<td>*</td>
<td>56</td>
<td>29</td>
</tr>
<tr>
<td>8 s (High)</td>
<td>41</td>
<td>118</td>
<td>94</td>
<td>40</td>
<td>58</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1126F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>23</td>
<td>10</td>
<td>36</td>
<td>31</td>
<td>34</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>9</td>
<td>6</td>
<td>53</td>
<td>28</td>
<td>55</td>
</tr>
<tr>
<td>2 s (Low)</td>
<td>2</td>
<td>34</td>
<td>34</td>
<td>29</td>
<td>54</td>
</tr>
<tr>
<td>2 s (High)</td>
<td>19</td>
<td>10</td>
<td>33</td>
<td>25</td>
<td>42</td>
</tr>
<tr>
<td>8 s (Low)</td>
<td>19</td>
<td>52.</td>
<td>56</td>
<td>41</td>
<td>62</td>
</tr>
<tr>
<td>8 s (High)</td>
<td>*</td>
<td>95</td>
<td>49</td>
<td>*</td>
<td>45</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1127F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>2</td>
<td>2</td>
<td>19</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2 s (Low)</td>
<td>12</td>
<td>7</td>
<td>18</td>
<td>*</td>
<td>10</td>
</tr>
<tr>
<td>2 s (High)</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>8 s (Low)</td>
<td>11</td>
<td>8</td>
<td>14</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>8 s (High)</td>
<td>*</td>
<td>*</td>
<td>18</td>
<td>16</td>
<td>20</td>
</tr>
</tbody>
</table>

Mean adjusting delay, to the nearest second, when stability was reached within a session in Condition 2 for subject’s 1125F, 1126F, and 1127F.

The data for subject 1132M are shown in Figure 15 and include the development of stable adjusting delays for 28 of the 30 sessions (indicated in Table 7). The two sessions when the subject did not show the development of indifference was with a standard delay of 8 s. Subject 1132M established similar indifference points when the standard delay was either 0.1 s or 2 s such as seen in the second week with means of 13 s (low start value) or 5 s (high start value) when the standard delay was 0.1 s and 21 s or 13
s when the standard delay was 2 s. Regardless of this similarity, indifference points were highest when the standard delay was 8 s at 42 s and 22 s in week 2.

Figures 16 and 17 show data for subjects 1134M and 1136M, respectively, who were exposed to 0.1 s, 4 s, and 16 s standard delays to one pellet. Both of these subjects also showed the development of stable indifference within the session for most of the sessions shown. Subject 1134M was unable to meet the within session stability criteria in 6 out of the final 30 sessions of Condition 2. Subject 1134M did not develop stable performance during the 1st and 2nd week with a 4 s standard delays and the 4th week for a 0.1 s standard delay. Some sessions during the second week did not meet the within session stability criteria because the subject did not complete at least thirty choice trials before the session terminated. During sessions when stability criteria were met, the performance of 1134M showed increasing adjusting delays with increased standard delays. For example, the mean adjusting delay ranged from 5 s to 22 s when the standard delay was 0.1 s, ranged from 17 s to 33 s when the standard delay was 4 s, and ranged from 12 s to 89 s when the standard delay was 16 s. This example also illustrates some of the similarities of indifference points across standard delays as the ranges overlap. An overlap of indifference points across standard delays was also seen in the performance of subject 1136M. The mean adjusting delays ranged from 6 s to 32 s when the standard delay was 0.1 s, ranged from 13 s to 27 s when the standard delay was 4 s, and ranged from 16 s (the lowest possible value) to 49 s when the standard delay was 16 s. The mean adjusting delays were virtually indistinguishable for sessions when the standard delay was either 0.1 s or 4 s and irrespective of the start value of the adjusting delay. The performance of subject 1136M met the within session stability criteria in all 30 sessions shown in
Table 7. The Mean Adjusting Delay at Indifference in Condition 2.

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1131M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>2</td>
<td>21</td>
<td>5</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>12</td>
<td>2</td>
<td>33</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>2 s (Low)</td>
<td>13</td>
<td>11</td>
<td>33</td>
<td>27</td>
<td>29</td>
</tr>
<tr>
<td>2 s (High)</td>
<td>23</td>
<td><em>(Not finish)</em></td>
<td>28</td>
<td>40</td>
<td>23</td>
</tr>
<tr>
<td>8 s (Low)</td>
<td>61</td>
<td>26</td>
<td>29</td>
<td>33</td>
<td>39</td>
</tr>
<tr>
<td>8 s (High)</td>
<td>33</td>
<td>29</td>
<td>26</td>
<td>33</td>
<td>34</td>
</tr>
<tr>
<td>1132M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>4</td>
<td>13</td>
<td>9</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>2</td>
<td>5</td>
<td>13</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>2 s (Low)</td>
<td>8</td>
<td>21</td>
<td>11</td>
<td>13</td>
<td>22</td>
</tr>
<tr>
<td>2 s (High)</td>
<td>12</td>
<td>13</td>
<td>12</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>8 s (Low)</td>
<td>16</td>
<td>42</td>
<td>29</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td>8 s (High)</td>
<td>32</td>
<td>22</td>
<td>32</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>1134M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>5</td>
<td>22</td>
<td>19</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>13</td>
<td>12</td>
<td>22</td>
<td>*</td>
<td>18</td>
</tr>
<tr>
<td>4 s (Low)</td>
<td>17</td>
<td>27</td>
<td>21</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>4 s (High)</td>
<td>*</td>
<td>* (Not finish)</td>
<td>23</td>
<td>33</td>
<td>28</td>
</tr>
<tr>
<td>16 s (Low)</td>
<td>12</td>
<td>*</td>
<td>39</td>
<td>43</td>
<td>48</td>
</tr>
<tr>
<td>16 s (High)</td>
<td>23</td>
<td>* (Not finish)</td>
<td>*</td>
<td>20</td>
<td>89</td>
</tr>
<tr>
<td>1136M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 s (Low)</td>
<td>12</td>
<td>22</td>
<td>9</td>
<td>17</td>
<td>6</td>
</tr>
<tr>
<td>0.1 s (High)</td>
<td>32</td>
<td>13</td>
<td>21</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>4 s (Low)</td>
<td>17</td>
<td>20</td>
<td>16</td>
<td>23</td>
<td>13</td>
</tr>
<tr>
<td>4 s (High)</td>
<td>23</td>
<td>18</td>
<td>27</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>16 s (Low)</td>
<td>48</td>
<td>23</td>
<td>27</td>
<td>22</td>
<td>16</td>
</tr>
<tr>
<td>16 s (High)</td>
<td>49</td>
<td>29</td>
<td>24</td>
<td>13</td>
<td>22</td>
</tr>
</tbody>
</table>

Mean adjusting delay, to the nearest second, when stability was reached within a session in Condition 2 for subjects 1131M, 1132M, 1134M, and 1136M.

Figure 17. However, stability was not reached until the final choice trials for two sessions (see Week 1 and Week 4). Despite the sometimes similar indifference
points, the mean adjusting delay was highest when the standard delay was 16 s even though only slightly higher during some sessions.

Some general trends were observed in the performance of all subjects in this experimental condition. First, indifference points were established for all subjects across standard delays (also seen in many sessions of Condition 1). Second, the mean adjusting delay at stability was similar when the starting value of the adjusting delay was high (20 s) or low (6 s). Third, the highest indifference points were observed when the standard delay was longest at either 8 s or 16 s. However, the mean adjusting delays at stability were somewhat similar across short standard delays of 0.1 s, 2 s, or 4 s. Finally, at least 80% of the sessions during this final five-week period (24 out of 30 sessions) included the development of stable indifference and hence early session termination.

Figure 18 provides summary plots of mean indifference points across standard delays during the final five-weeks of Condition 2. Each mean adjusting delays was determined across the final 10 trials of the five individual sessions shown in Figures 11 through 17. The open symbols show data when the adjusting delay started at a low value of 6 s; the closed symbols show data when the adjusting delay started at 20 s. The mean adjusting delays at indifference for several subjects (1125F, 1126F, 1127F, and 1132F) were almost the same when the standard delay to one pellet was either 0.1 s or 2 s suggesting that a change in the delay from 0.1 s to 2 s does not alter the subjective value of one pellet by much. The mean indifference points for subjects 1134M and 1136M were closely approximated when the delay to one pellet was 0.1 s or 4 s. As previously
Figure 11. Condition 2 for subject 1125F. This figure shows within-session data for the final five weeks of the second condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols). The vertical dotted line at trial 30 indicates the trial after which stability was determined within the session.
Week 1

Week 2

Week 3

Week 4

Week 5

Trials Within a Session

Adjusting delay (sec)

8 s (Low)
0.1 s (Low)
2 s (High)
0.1 s (High)
8 s (High)
2 s (Low)

Week 1

Week 2

Week 3

Week 4

Week 5

Trials Within a Session

Adjusting delay (sec)

8 s (Low)
0.1 s (Low)
2 s (High)
0.1 s (High)
8 s (High)
2 s (Low)

Week 1

Week 2

Week 3

Week 4

Week 5

Trials Within a Session

Adjusting delay (sec)

8 s (Low)
0.1 s (Low)
2 s (High)
0.1 s (High)
8 s (High)
2 s (Low)

Week 1

Week 2

Week 3

Week 4

Week 5

Trials Within a Session

Adjusting delay (sec)

8 s (Low)
0.1 s (Low)
2 s (High)
0.1 s (High)
8 s (High)
2 s (Low)

Week 1

Week 2

Week 3

Week 4

Week 5

Trials Within a Session

Adjusting delay (sec)

8 s (Low)
0.1 s (Low)
2 s (High)
0.1 s (High)
8 s (High)
2 s (Low)

Week 1

Week 2

Week 3

Week 4

Week 5

Trials Within a Session

Adjusting delay (sec)

8 s (Low)
0.1 s (Low)
2 s (High)
0.1 s (High)
8 s (High)
2 s (Low)
Figure 12. Condition 2 for subject 1126F. This figure shows within-session data for the final five weeks of the second condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols). The vertical dotted line at trial 30 indicates the trial after which stability was determined within the session.
Adjusting delay (sec)

Week 1

Week 2

Week 3

Week 4

Week 5

Trials Within a Session

1126F

8 s (Low)
0.1 s (Low)
2 s (High)
0.1 s (High)
8 s (High)
2 s (Low)

0.1 s (Low)
2 s (Low)
8 s (High)
8 s (Low)
2 s (High)
0.1 s (High)

0.1 s (Low)
8 s (High)
0.1 s (High)
2 s (High)
8 s (Low)
2 s (High)

2 s (Low)
0.1 s (High)
8 s (Low)
4 s (High)
0.1 s (Low)
8 s (High)

8 s (High)
2 s (Low)
2 s (High)
0.1 s (Low)
0.1 s (High)
16 s (Low)
Figure 13. Condition 2 for subject 1127F. This figure shows within-session data for the final five weeks of the second condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols). The vertical dotted line at trial 30 indicates the trial after which stability was determined within the session.
Figure 14. Condition 2 for subject 1131M. This figure shows within-session data for the final five weeks of the second condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols). The vertical dotted line at trial 30 indicates the trial after which stability was determined within the session.
Adjusting delay (sec)

Week 1

Week 2

Week 3

Week 4

Week 5

Trials Within a Session

8 s (Low)
0.1 s (Low)
2 s (High)
0.1 s (High)
8 s (High)
2 s (Low)
0.1 s (Low)
8 s (Low)
2 s (High)
0.1 s (High)
8 s (Low)
2 s (High)
0.1 s (Low)
8 s (High)
2 s (Low)
0.1 s (Low)
8 s (Low)
2 s (High)
0.1 s (Low)
8 s (Low)
Figure 15. Condition 2 for subject 1132M. This figure shows within-session data for the final five weeks of the second condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols). The vertical dotted line at trial 30 indicates the trial after which stability was determined within the session.
Figure 16. Condition 2 for subject 1134M. This figure shows within-session data for the final five weeks of the second condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols). The vertical dotted line at trial 30 indicates the trial after which stability was determined within the session.
Figure 17. Condition 2 for subject 1136M. This figure shows within-session data for the final five weeks of the second condition. Each graph plots the adjusting delay in seconds across trials within the session for all six sessions of each week. The graphs include two sessions with the same standard delay (same symbols) when the adjusting delay started at either 6 s (open symbols) or 20 s (filled symbols). The vertical dotted line at trial 30 indicates the trial after which stability was determined within the session.
Figure 18. Condition 2 summary plot. This figure shows mean adjusting delay and 99% confidence intervals of the data in the second experimental condition over the last ten trials as a function of the standard delay. The open symbols show data from sessions during which the adjusting delay started at 6 s and the filled symbols plot data from when the adjusting delay started at 20 s.

noted, all of the subjects maintained the highest indifference points with the highest standard delay of 8 s or 16 s. The figure also demonstrates the similarity of indifference points with the same standard delay regardless of the starting value of the adjusting delay.
This summary figure also demonstrates the linear changes in indifference points as the standard delay increased.

Figure 19 summarizes the data shown in Figure 18 including a single mean indifference point across each standard delay. Each mean adjusting delay was determined by combining the data from the final 10 trials reaching stability when the adjusting delay began the session at 6 s or 20 s. A line was then fitted to the data describing the changes in the indifference point as a function of the standard delay to one pellet. Figure 18 are indifference curves of the obtained mean adjusting delays at indifference. Figure 19 are discount curves of best fitting lines. All of the individual performance analyses produced positive y-intercepts and slopes. The y-intercepts were approximately 20 s for four of the seven subjects (1126F, 1131M, 1134M, and 1136M) with a range of 5.31 to 23.74. These findings suggest that when the delay to one pellet was near zero, a delay between 5 and 24 s to three pellets was required to make them equally preferred or chosen with equal frequency by the subjects. Analysis of individual subject performance show slopes ranging from 1 to 6. The slope summarizes how a change in the delay to the delivery of one pellet influences the adjusting delay to three pellets that will produce equal preference or responding between the two alternatives. If the slope is high, a change in the delay to one reinforcer alternative will then require a large change in the adjusting delay to the other alternative before both are equally preferred. If the slope is low, a change in the delay to one reinforcer alternative will then require a small change in the adjusting delay to the other alternative before both are equally preferred. The slopes were lower for the two subjects exposed to standard delays of 0.1 s, 4 s, or 16 s (1.1 and 1.49) than for subjects exposed to standard delays of 0.1 s, 2
Figure 19. Linear Regressions for Condition 2. This figure shows scatter plots of the mean adjusting delay as a function of the standard delay during the final sessions of the second condition. The mean adjusting delay during the final ten choice trials of the session when the adjusting delay began at either 6 or 20 s contribute to calculations of the mean (n=20 trials). A linear regression is fitted to each subject’s data and a group analyses is in the bottom right plot.
\[ y = 5.8x + 12.21 \]
\[ r^2 = 0.996 \]

\[ y = 3.2x + 25.78 \]
\[ r^2 = 0.983 \]

\[ y = 1.67x + 5.31 \]
\[ r^2 = 0.992 \]

\[ y = 2x + 21.45 \]
\[ r^2 = 0.8773 \]

\[ y = 1.49x + 17.95 \]
\[ r^2 = 0.99 \]

\[ y = 1.1x + 23.74 \]
\[ r^2 = 0.99 \]

\[ y = 1.64x + 18.9 \]
\[ r^2 = 0.858 \]
s, or 8 s (5.8, 3.2, 1.67, 2, and 2.68). The variance accounted for by the fitted line ranged from 87% to 99% for individual subject data. The bottom right plot shows a linear regression analysis for the mean across all of the subjects in this experiment. The analysis accounted for 86% of the variability with a slope of 1.64 and an intercept of 18.9. The largest discrepancy from the fitted line was observed at the 8 s standard delay. The group analysis produced slope and y-intercept parameters very similar to those found with individual performances of the subjects.

Figure 20 shows linear regression analyses for the group data from the final sessions of the first and second experimental conditions. Both scatter plots show the mean adjusting delay for all subjects during the ten-trial block that reached the within session stability criteria. The linear regression analyses showed positive y-intercepts and slopes during both experimental conditions although both the slope and intercept decreased across conditions. For instance, the y-intercept was 19.84 s at the end of the

![Figure 20](image-url)

Figure 20. Linear regression comparisons for Conditions 1 and 2. This figure shows summary data for all of the subjects in the first and second experimental conditions. A group mean adjusting delay, seconds, is shown as a function of the standard delay are shown in the scatter plot along with a linear regression analysis.
first but 18.9 s at the end of the second experimental condition. The amount of variability accounted for by the linear regression was higher for the second experimental condition.

**Condition 3.** Figures 21 and 22 show data from sessions in the second and third experimental conditions. The mean adjusting delay during the final 10 choice trials of the sessions is plotted as a function of sessions. The left column shows data when the standard delay changed each day of the week (second experimental condition) and the right column of each plot shows data when the standard delay remained the same (third experimental condition). Open symbols are mean adjusting delays when the delay started the session at a low value of 6 s while the filled symbols are means when the delay started at a high value of 20 s. Data for six of the original seven subjects are shown in Figures 21 and 22. One subject (1125F) was lost during the early sessions of the third experimental condition thus those data were omitted. Across-session variability was seen in the adjusting delays across sessions in both experimental conditions and similar amounts of variability were detected in both conditions.

The two top rows of Figure 21 include data for subject’s 1126F and 1127F. The indifference points for subject 1126F are in the top row of Figure 21. As in the other experimental conditions, the lowest indifference points were observed when the standard delay was 0.1 s than when it was 2 s or 8 s. This pattern became more pronounced in Condition 3 as evidenced by less nominal similarity of indifference points across standard delays. This pattern was consistent when the adjusting delay began a session at high or low value. The second row of graphs in Figure 21 is data for subject 1127F. The mean adjusting delay varied between 5 s and 40 s across standard delays in both conditions although most indifference points were near or below 20 s. The indifference points
varied across sessions although similar levels of variability were detected across both conditions. In Condition 3, the mean adjusting delays were similar when the standard delay was 0.1 s or 2 s with ranges of 2 s to 10 s and 3 s to 14 s, respectively. The range of indifference points was a little higher when the standard delay was 8 s with a range of 8 s to 40 s. The mean adjusting delays were also similar across standard delays in Condition 2.

The performance of subjects 1131M and 1132M is shown in the bottom portion of Figure 21. Mean adjusting delays observed in Condition 2 for subject 1131M ranged from 2 s to 37 s, 4 s to 39 s, and 27 s to 49 s when the standard delays were 0.1 s, 2 s, or 8 s, respectively. Such ranges in indifference points clearly include a large deal of overlap when the standard delays were 0.1 s or 2 s. Similarly for subject 1131M in Condition 3, the indifference points ranged from 9 s to 29 s, 5 s to 35 s, and 15 s to 57 s when the standard delays were 0.1, 2, or 8 s, respectively. Again, the indifference points overlapped when the standard delays were either 0.1 s or 2 s but were higher when the standard delay was 8 s. The performance of subject 1132M as shown in the bottom row of Figure 20. The indifference points ranged from 2 s to 13 s, 9 s to 26 s, and 16 s to 43 s when the standard delay was 0.1 s, 2 s, or 8 s in Condition 2. Similarly, the indifference points ranged from 2 s to 12 s, 2 s to 18 s, and 10 s to 98 s when the standard delay was 0.1 s, 2 s, or 8 s in Condition 3. The upper range of indifference points increased with increased standard delays in both experimental conditions despite the overlap observed across standard delays. The performance of this subject showed less across session variability in Condition 3 than observed in Condition 2.
Figure 22 shows data for subjects 1134M and 1136M. The data for subject 1134M are shown in the top row of Figure 21. Data from two sessions are missing from Condition 3 for this subject. Note that the symbols are the same for the same standard delays shown in Figure 21 but that subjects 1134M and 1136M were exposed to a new standard delay during this final condition of the experiment. These two subjects were originally presented with 0.1 s, 4 s, or 16 s standard delays and the 2 s standard delay was added during the final condition. As would be expected from the findings in the previous two experimental conditions, the mean adjusting delays with a 2 s and 4 s standard were very similar showing minor differences in the influence of these two delays on the indifference points for subject 1134M. During Condition 2, the indifference points ranged from 6 s to 69 s, 6 s to 55 s, and 29 s to 103 s when the standard delay was 0.1 s, 4 s, or 16 s. Interestingly, the indifference points only ranged from 15 s to 50 s across all of the standard delays (0.1, 2, 4, or 16 s) in the third experimental condition. In other words, this subject showed less across session variability during Condition 3 than was observed in Condition 2. The mean adjusting delays shown by subject 1136M were more variable during the fixed standard delay condition than those observed when the standard delay alternated daily (Condition 2). For instance, the mean adjusting delays ranged from 26 s to 50 s during the final week of the third experimental condition when the standard delay was 16 s but only ranged from 40 s to 50 s in the second experimental condition. The indifference point was highest when the standard delay was 16 s and lowest when the standard delay was 0.1 s across both conditions for subject 1136M. Performance in Condition 2 appeared to include a decreasing trend in indifference points across standard delays suggesting that performance was not yet stable at the termination of Condition 2.
Figure 21. Mean indifference points across sessions in Conditions 2 and 3. The mean adjusting delay during last ten trials of a session across sessions for subject’s 1126F, 1127F, 1131M, and 1132M are shown in the individual plots. The left column includes data from the second experimental condition when a different standard delay was presented daily and the right column includes data from the third experimental condition when the standard delay was constant for an entire five-week regimen. Filled symbols are sessions when the adjusting delay began the session at 6 s and the open symbols are sessions when the adjusting delay began at 20 s.
Figure 23. Mean adjusting delay in Conditions 2 and 3 for subjects 1134M and 1136M. The mean adjusting delay during last ten trials of a session across sessions for subjects 1134M and 1136M are plotted. The left column includes data from the second experimental condition when a different standard delay was presented daily and the right column includes data from the third experimental condition when the standard delay was constant for a three five-week regimens.

In summary, subjects were able to meet the within-session stability criteria although indifference points varied from session to session with the same standard delay.
This variability was observed whether the standard delay changed each day (Condition 2) or remained fixed (Condition 3). The performance of subjects 1131M, 1132M, 1134M, and 1136M showed slightly less variability when the standard delay remained fixed from session-to-session.

Figure 23 is a summary plot of the data in Condition 1. Each graph shows the mean adjusting delay at indifference when the within session stability criteria were met. Each indifference point was determined as the mean adjusting delay of the within session mean adjusting delay. The filled symbols indicate the means when the adjusting delay was 20 s at the beginning of each session while the open symbols indicate sessions when the adjusting delay was 6 s. A 95% confidence interval is indicated by the error bars but indicate much less variability than was observed in Condition 1 or Condition 2 performances. Indifference points were not consistently modified by the adjusting delay at the beginning of the session but instead the indifference points were similar whether the adjusting delay was 20 s or 6 s at the beginning of the session. The summary plot demonstrates some across session variability in the indifference point in sessions with the same standard delay but an increasing indifference point with increased standard delays to one pellet. Note that the indifference curve includes the standard delay of 2 s for subjects 1134M and 1136M during Condition 3 only. The mean adjusting delay at indifference was similar when the standard delay was 2 or 4 s for these subjects.

Discussion

The findings from Experiment 2 demonstrate the use of a fast adjusting-delay procedure to obtain indifference points and delay discount functions with rats. All subjects developed stable indifference points within an experimental session even in conditions
when a different standard delay was presented each day of the week. Indifference points increased with increased standard delays. Beginning a session with a low and high start

Figure 23. Condition 3 mean indifference points. Each graph includes the mean adjusting delay across sessions with a 95% confidence interval. The open symbols indicate sessions when the standard delay was 6 s at the start of the session while filled symbols indicate a 20 s adjusting delay at the start of the session.
adjusting delay value did not produce consistently different indifference points. The current findings extend the procedure proposed by Richards et al. (1997) from a rapid adjusting procedure during which the amount of immediate reinforcement adjusted across trials to a procedure where the delay to the larger, delayed reinforcer adjusted. Furthermore, the data from Condition 2 showed that indifference points could be established using a rapid adjusting delay procedure in sessions lasting only 40 choice trials or approximately 35 minutes. One limitation of the procedure was the observed across-session variability of the mean adjusting delay at indifference. This variability was similar when a different standard delay was presented each day (Conditions 1 and 2) and when the same standard delay was presented each day (Condition 3) suggesting that daily changes in the standard delay was not the variable responsible for the observed variability. This level of variability in individual subject performances would make detection of the influence of other independent variables on performance difficult. It is unclear which variable(s) of the current procedure is responsible for producing this variability. The data reported by Richards et al. (1997) also included variability across subjects most clearly indicated from the fitted parameter ranges of 0.07 to 0.32 for k (the discount parameter) and bias parameters ranging from 0.59 to 1.52.

A general pattern demonstrated by within-session changes in the adjusting delay across trials during Condition 1 was the establishment of stable indifference followed by unstable performance for the remainder of the session or followed by the development of a second indifference point. One possible reason for this performance may have been that subjects became satiated during the course of the session. For instance, subject 1134M showed the development of indifference followed by consistent preference for the
standard alternative for the remainder of the session (Week 2 when the standard delay was 16 s). Several lines of evidence argue against such an account. First, this subject was able to develop stable indifference during the other sessions that week. So why would satiation be selectively observed during only one session? Second, research examining the influence of deprivation levels on self-control choice have provided inconsistent affects on choice. Several researchers have reported no effect (Logue, Chavarro, Rachlin, and Reeder 1988; Logue and Peña-Correal 1985), some reporting decreased self-control with increased deprivation (Eisenberger and Masterson 1987; Eisenberger et al. 1982; Snyderman 1983), and others reporting increased self-control (mean adjusting delays at indifference) with increased deprivation (Bradshaw and Szabadi 1992; 1993; Christensen-Szalanski, Goldberg, Anderson and Mitchell 1980; Ho et al. 1997; Wogar et al. 1992).

One of the potential benefits of the fast adjusting procedure is the rapid development of indifference points across standard delays. One methodological question of interest was whether stable indifference points could be obtained in comparable time with a fast adjusting-delay procedure as compared to that reported by Richards et al. (1993) with a fast adjusting-amount procedure. The total time of exposure to the current procedure in Experiment 2 was approximately 55 weeks or 11 months. This is longer than the time taken to establish indifference that was reported by Richards et al. (1997) where it took only 15 weeks. Part of the reason for the added time in the current experiment was to conduct some manipulations that were not included in Experiment 1 of Richards et al. (1997). The first experimental condition is the most comparable to the findings from Experiment 1 of Richards et al. (1997). Figures 5 through 11 are data from
the 20th week showing the development of indifference within the session for many of the standard delays. The data shown in these figures suggest that a fast-adjusting delay procedure can be used to successfully establish indifference points in approximately the same time required to establish indifference points with an adjusting-amount procedure.

The current experimental findings shared several other similarities with those reported by Richards et al. (1997). One similarity was that the value of reinforcers decreased with increased delays to their receipt. The data from Richards et al. (1997) showed that as the delay to the larger amount of water was increased, the adjusted amount of immediate water at indifference decreased. The rats preferred the smaller, more immediate amount of water as the delay to the larger amount was increased. The current experimental findings showed increasing adjusting delays with increased delays to the standard alternative. In other words, the rats in the current experiment preferred the larger, more delayed reinforcer when the delay to the smaller reinforcer was increased. Another similarity was that both experiments provide support for a hyperbolic function to describe the influence of reinforcement parameters on self-control choice.

Comparison of the data from Condition 1 and Condition 2 as shown in Figure 19 showed that both the y-intercept and discount parameter, k, decreased. It is unclear why this decrease was observed. It is possible that the history with the standard delays modified the influence of other delays in a manner similar to that observed in Experiment 1. This is not supported by a consistently higher or lower indifference point as a function of the standard delay presented during the preceding session. Another possibility is that performance was more stable by the end of Condition 2 than it was at the end of Condition 1. This contention is supported by the higher number of sessions where the
within-session stability criteria were met in Condition 2 than in Condition 1 (see Tables 4, 5, 6, and 7).

The within-session changes in the adjusting delay showed substantial fluctuations in the indifference point within the same session, as evidenced by sessions where more than one indifference point was obtained within the same experimental session in Condition 1. Variability was also demonstrated across sessions with the same standard delay as shown in Figures 21 and 22. It is unclear from previous experimental reports whether this level of across session variability has also been detected as most of the reports in the literature include mean indifference curves and/or discount functions (Mazur 1987; 1988; Ho et al. 1997; Wogar et al. 1993; 1992).
CHAPTER 4
GENERAL DISCUSSION

The current experiments were designed to investigate the choice behavior of rats when choosing between a large, delayed reinforcer and a small, more immediate one. Experiment 1 demonstrated that most (5 out of 6) rats exclusively chose three pellets delayed by 6, 12, or 24 s over one pellet presented immediately. Rats reversed their preference and chose one pellet presented immediately when the delay to three pellets was increased to 48 s. Previous research shows that pigeons are likely to make impulsive choices, i.e., choose the small, more immediate reinforcer under similar conditions (see review by Logue 1988). One question that remained following the completion of Experiment 1 was whether the observed differences in self-control choice patterns of rats and pigeons were the result of a quantitative or qualitative difference in self-control choice patterns as a function of increased delays. A quantitative difference would be evident by similar forms in the function relating changes in preference to delay increases. Different forms of the function would be indicative of a qualitative difference across species. Experiment 2 was designed to address this question by utilizing an adjusting-delay procedure. In an adjusting-delay procedure, the delay to the large reinforcer changed across choice trials as a function of a subject’s choice patterns. The delay that produced equal responding for both alternatives (the small, more immediate versus the large, delayed option) defined the indifference point. Summary plots of indifference points as a function of increased delays to one pellet were used to calculate
linear regressions. The linear regressions demonstrated similar functions with positive slope and y-intercepts across subjects in Experiment 2. These findings are consistent with findings previously reported with pigeons (Mazur 1987; 1988; Logue et al. 1984), with rats in a standard adjusting delay procedure (Ho et al. 1993; Mazur et al. 1987; Richards et al. 1997; Tobin et al. 1993; Wogar et al. 1992; 1993), and humans (Bickel et al. 1999; Green, Fristoe, and Myerson 1994; Green, Fry, and Myerson 1994; Green et al. 1997; Rachlin et al. 1991; Richards et al. 1999). Thus, the data suggest qualitative similarity across species.

The indifference points were variable in conditions where the standard delays changed daily (Experiment 2, Conditions 1 and 2) or when the standard delay was fixed (Experiment 2, Condition 3). Changing the standard delay daily did not result in a contrast effect on the indifference points. Comparisons of the data shown in Figures 21 and 22 show no systematic influence of the standard delay from the previous session. A contrast effect would be a consistently higher or lower indifference point as a function of the standard delay during the previous session being low (0.1 s) or high (8 s or 16 s). Session-to-session variability was observed across sessions with the same standard delay in both Conditions 2 and 3. Subjects 1132M, 1134M, and 1136M were the only subjects demonstrating less variable performance when only one standard delay was presented each day of the week suggesting that a daily change in the standard delay may have increased variability for some subjects. Future research is needed to determine which variable(s) were responsible for the observed variability.

The data from Experiment 1 suggest that the manner of delay introduction may have attenuated the effects of delay on self-control choice. When subjects were given a history
of delays of 6 s, 12 s, and then 24 s prior to the delivery of three pellets, they made almost exclusive choices for three pellets over one pellet immediately presented (programmed delay of 0.1 s). Choice patterns reversed when subjects then made a choice between one pellet delayed by 0.1 s and three pellets delayed by 48 s. Preference for one pellet was then maintained when the delay to three pellets decreased to 24 s from 48 s while the opposite pattern was seen when a 24 s delay was preceded by a 12 s delay condition. Similar order effects were observed in the performance of subject 132F who showed preference for 1 pellet immediately over 3 pellets after a 6 s delay. Preference switched to near exclusive choice of three pellets when the delay was decreased to 3 s. This preference was maintained when the delay to 3 pellets was increased to 6 s. This demonstrated that the influence of stimulus presentation on behavior depends on a subject’s history with that stimulus presentation. Similar findings have been reported with pigeons making self-control choices for food reinforcers (Logue and Mazur 1981; Mazur and Logue 1978). Mazur and Logue (1978) found that a gradual decrease in the delay to a small, more immediate reinforcer would result in higher responding for the self-control choice alternative than when subjects were not provided with such a history. Comparison of discount functions from Condition 1 and 2 from Experiment 2 also suggest that a history with a fast adjusting-delay procedure may attenuate the affects of delay on self-control choice. Both the slope and y-intercepts of the discount functions decreased over time.

The findings from Experiment 2 are consistent with those reported in Experiment 1 in terms of the delay to the larger reinforcer at which preference reversed. In Experiment 1, five of the six subjects made close to 100% choices for the large, delayed reinforcer (3
pellets) until it was delayed by more than 24 s although one subject made impulsive choices when the large reinforcer was delayed by only 6 s. This is consistent with the findings of Experiment 2 with indifference between one pellet available following a 0.1 s delay and three pellets was following a delay ranging from 5 s to 24 s. These findings are also consistent with those reported by van Haaren et al. (1988) but not those reported by Logan (1965), Eisenberger and Masterson (1987), Eisenberger, Masterson, and Lowman (1982), or Tobin et al. (1993) showing preference reversals at shorter delays. Logan (1965) found a reversal in preference from one pellet immediately when the delay to three pellets ranged from 8 s to 12 s in a double-alley maze choice task.

It is unclear why the subjects in Experiment 2 showed indifference between 1 pellet now and 3 pellets after a delay of approximately 20 s but showed exclusive self-control choice at a 24 s delay in Experiment 1 when a non-adjusting procedure was used. The non-adjusting procedure was seen to produce bimodal effects on preference with subjects exclusively preferring only one alternative during a given delay condition. One possibility is that a delay of 24 s would produce near indifference in an adjusting delay procedure but not be large enough to produce exclusive impulsivity in a fixed delay procedure. Consistent with this argument is the documented enhancement of preference when a discrete-trial choice arrangement is used as only a few choice responses are permitted (de Villiers 1977). In a discrete-trial choice arrangement, the subject makes one or a few responses that comprise a choice and initiate the delay to reinforcer delivery. The main dependent measure in this type of arrangement is the number of choice or percentage of choices allocated to each alternative. This can be contrasted with a concurrent choice arrangement where responding on either alternative can initiate the
delay to reinforcer delivery only with the first response following some variable amount of time (concurrent variable-interval schedules). The main dependent measure is the relative number of responses not choices for a given reinforcer alternative. This second type of choice arrangement produces more graded measures of preference. Although both of the choice procedures used in the current experiments were discrete-trial, only a few (three) responses defined the choice response and initiated reinforcer delays, the adjusting-delay procedure allowed for direct detection of the delay producing indifferent responding while the fixed delays used in Experiment 1 only allowed for interpolation of that delay. The dependent measure utilized in Experiment 2 was thus a much more graded measure of preference changes with increased delays. Also, the adjusting delay measures the indifference point, not preference reversal.

The current findings demonstrated that reinforcer value decreased with increased delays; a finding consistent with previous research. Furthermore, the manner in which reinforcer value decreased with increasing delays was consistent with the predictions made by the hyperbolic equation. This equation has also been consistently supported with findings reported using pigeons (e.g., Mazur 1987; 1988; Logue et al. 1984), with rats in a standard adjusting delay procedure (Ho et al. 1997; Mazur, et al. 1987; Richards et al. 1997; Tobin et al. 1993; Wogar, et al. 1992; 1993), and humans (Bickel et al. 1999; Green, Fristoe, and Myerson 1994; Green, Fry, and Masterson 1994; Green et al. 1997; Rachlin et al. 1991; Richards et al. 1999). Richards et al. (1997) showed that as the delay to 100 µl of water increased, preference for that alternative decreased; in other words, more responding for the immediate amount of water was observed. Responding for the immediate amount of water produced decreased amounts of water associated with that
alternative at indifference. The function between the adjusted amount of immediate water (the value of µL presented immediately) as a function of the standard delay to 100 µL of water included slopes ranging from 0.07 to 0.36 and bias parameters (b) ranging from 0.78 to 1.52. A hyperbolic discount function accurately described both individual subject performances and the group mean. Similar relations where shown by Richards et al., (1999) when using human subjects making choices for an adjusting amount of immediate money delivery versus a standard but larger amount of money ($10) that followed a delay ranging from 0 to 365 days or probability ranging from 0.25 to 1.0. When the delay to $10 dollars was only a few days, subjects preferred that alternative and as a result produced a decrease in the adjusting amount of immediate money. However, when the delay to $10 increased, subjects began to choose the immediate amount of money thereby decreasing the amount immediately available. A hyperbolic discount function was able to accurately describe the function relating changes in the value of the immediate amount of money as a function of the delay to the larger alternative and as a function of the odds against obtaining the larger alternative reinforcer. The data from Experiment 2 showed increased mean indifference points to three pellets (increased value of that alternative) when the delay to one pellet increased from 0.1 s to 8 s or 16 s. A hyperbolic discount equation predicts positive slope and y-intercepts of the function relating mean adjusting delay to the large reinforcer as a function of increased delay to the smaller, standard alternative. Both of these predictions were supported by the findings from Experiment 2.

The current findings distinguish between several decay functions and suggest that the hyperbolic function is the most adequate. Several other decay models have been
proposed that share similar assumptions. First, the equations describe a value function that is concave downward and that approaches a value of 0 as the delay approaches infinity. Each equation includes a parameter $A$ that is assumed to be monotonically related to amount of reinforcement such that $A$ is assumed to be larger for three pellets than one pellet. No assumptions are made about exactly how much larger three pellets are than one and reinforcer value is assumed proportional to $A$. Each equation includes a delay parameter ($D$) and a discount parameter of $K$ than can vary to account for individual differences among procedures or subjects. The predictions of each of these models are shown in Figure 24.

![Graph of Delay Functions](image)

Figure 24. Illustrative predictions of three decay functions.

A simple reciprocal model of choice similar to the one proposed by Baum and Rachlin (1969) specifies reinforcer value as a direct function of reinforcer amount and an inverse function of delay as shown in equation 4-1 below.

$$V = \frac{A}{KD}$$  \hspace{1cm} (4-1)
As indicated by the solid line in Figure 24, this model predicts that as the delay approximates 0 s, the value of that reinforcer approaches infinity. Such a prediction is problematic in that it predicts that an immediate reinforcer will always be preferred to one with a delay, even a short delay. This prediction was not supported by the findings from Experiment 1. This model also predicts a linear indifference curve will have a y-intercept of 0 and a slope that depends on the relative amounts of the two reinforcers. Positive y-intercepts were found for all subjects in Experiment 2 not supporting a simple reciprocal model.

An exponential model of choice, similar to Hull’s (1943) delay function, specifies that reinforcer value is a direct function of the amount of reinforcement and exponentially modified by the delay to its receipt discounted by parameter k as shown in equation 4-2 below.

\[ V = A e^{-kD} \]  

(4-2)

The predictions of this model are illustrated by the dashed line in Figure 24. An exponential model of choice has the immediate problem of not predicting the well document reversal of preference (see review by Logue 1988). This model predicts a linear relationship between the adjusting delay and the standard delay. Furthermore, this model predicts a slope of 1.0 and a positive intercept that varies as a function of the relative amounts of reinforcement. This model is not supported by the slopes greater than 1.0 found across subjects in Experiment 2. The hyperbolic function also predicts a linear equation fitted to the indifference curve with a positive intercept and slope greater than 1. These predictions of the hyperbolic model of choice were supported by the current findings from Experiment 2 and consistently reported using a standard- or fast-adjusting
procedure, different reinforcers, and/or different species (Ho et al. 1997; Logue et al. 1984; Mazur 1987; 1988; Mazur et al. 1987; Wogar, et al. 1992; 1993). Comparison of the linear regressions shown in Figure 19 to the predictions of the three equations shown in Figure 23 demonstrates that the hyperbolic equation (the dotted line) makes predictions most consistent with the findings from Experiment 2.

The linear discount functions from Experiment 2 included slopes similar to those previously reported across species and adjusting procedures with nominally higher y-intercepts (Ho et al. 1999; Mazur 1987; 1988; Mazur, Stellar, and Warcynski 1987). For instance, Mazur et al. (1987) presented rats with a choice between a small reinforcer of low frequency electrical brain stimulation following a fixed delay, ranging from 0 to 10 s, and a large reinforcer of high frequency electrical brain stimulation following an adjusting delay. The linear regressions were fitted to the individual performances of all three rats producing slopes ranging from 1.3 to 3.9 and y-intercepts from 6.5 to 8.2. These findings overlap the parameters found in Experiment 2 when linear regressions were fitted to the individual data of all seven subjects producing slopes ranging from 1 to 6 but sometimes much higher y-intercepts with ranges from 5 to 26. A similar range of slopes was reported by Mazur (1987) when presenting pigeons with a choice between two seconds of grain access following a standard delay ranging from 0 to 20 s and six seconds of grain that followed an adjusting delay. The regression lines fitted to the data for these four subjects produced slopes of 2.6, 2.2, 2.7, and 2.0 with y-intercepts of 0.3, 4.1, 0.3, and 5.8, respectively. Although all three of these experiments reported similar slopes albeit individual subject variability, the y-intercepts showed ranges that did not always overlap. Mazur (1987) reported a range of y-intercepts that was lower than that
reported by Mazur, Stellar, and Warcynski (1987) or found in Experiment 2. The difference in y-intercepts cannot be completely attributed to different experimental procedures as Ho et al. (1993) conducted an experiment using the standard adjusting delay procedure to examine choice behavior of rats and reported findings similar to those seen in the current Experiment 2. In their procedure, rats were presented with a choice between 1 pellet following a delay of 2 s, 4 s, or 8 s and two pellets following an adjusting delay. Ho et al. (1997) found a mean y-intercept of 19.5 similar to the slope in the current findings with a y-intercept of 18.9 using a new fast adjusting procedure. The slopes were also similar with Ho et al. (1997) finding a group mean slope of 2.3 and and our current group mean of 1.64. Grossbard and Mazur (1986) reported y-intercepts and slopes of their discount functions similar to those found in Experiment 2. Grossbard and Mazur (1987) presented pigeons with a self-control choice using the adjusting-delay procedure proposed by Mazur (1987). Pigeons were presented with a choice between small (2 s) or large amounts (6 s) of food presented following a fixed time or completion of a response ratio (producing approximately the same amount of time as in the fixed time conditions). The best fitting lines included positive slopes ranging from 1.55 to 2.30 and y-intercepts ranging from 0.7 to 17.6 (1.2, 6.3, 17.6, 11.9, 1.8, 4.1, 4.3, 4.0, 4.0, 2.8, 0.7, 2.2). The slopes reported by Grossbard and Mazur (1987) are much more similar to those currently reported suggesting that this observed differences may not be attributable to a species difference but may the result of some procedural or historical variable.

It is unclear what variable(s) is responsible for the observed differences in percentage of self-control choices (Experiment 1) and higher y-intercepts from those previously reported (Experiment 2). One possibility is that choice in pigeons may be more
influenced by the Pavlovian relationship between the presentation of a stimulus (stimulus light) and the delay to the food than by the operant consequences following a choice. It is well known that a close temporal contiguity between a signal and food elicits signal-directed behavior in pigeons. In addition, the longer the delay between presentation of the stimulus and food, the less signal directed behavior would be elicited (see review by Schwartz and Gamzu, 1977). Chelonis and Logue (1996) recently investigated this account by examining pigeons’ sensitivity to amount and delay of reinforcement across response topographies. Pigeons made self-control choices in a concurrent chain variable–interval (VI) 30-s schedule by either responding on an illuminated key or by pressing a treadle. Completion of the dependent VI schedule requirements initiated a terminal link delay to food delivery of 10 or 30 s. Pigeons exhibited response rates that were similar across different response topographies and preference was not differentially affected by terminal link manipulations of amount and delay to reinforcement across response topographies.

Another variable that may contribute to the quantitative differences observed across species could be due to non-equivalent relative reinforcer values; the relative value of 1 pellet versus three pellets may be different from that of 2 s versus 6 s of access to grain. This account is supported by research done by Epstein (1985) that showed a negatively accelerated relationship between the duration of hopper access and the amount of grain consumed. Generalizing these findings to the current findings is limited as that experiment did not compare equivalency of hopper duration to pellet delivery. Future research investigating this relationship is needed. Several experiments using adjusting delay procedures suggest that reinforcer size can influence the indifference point (Wogar
et al. 1992) and the discount curves (Green et al. 1994; Kirby and Marakovic 1996; Myerson and Green 1995; Raineri and Rachlin 1993). Evidence from several experiments with human subjects suggest that changes in reinforcer size influence the delay discount parameter, K, and no consistent changes in the bias (b) parameter. These findings were not supported by those reported from Experiment III of Richards et al. (1997) that showed no statistically significant difference in delay discounting parameter, K, or bias parameters across different standard amounts of water reinforcement in a rapid adjusting amount procedure. Furthermore and already noted, the current findings from Experiment 2 found delay discount parameters (the slope of the linear regressions) consistent with those previously reported in the literature. It is possible that higher y-intercepts observed in Experiment 2 are due to a lack in relative reinforcer size between the two alternatives. A direct examination of how increasing the absolute but not relative size of the reinforcers influenced indifference points was shown by Wogar, Bradshaw, and Szabadi (1992). Wogar et al. (1992) examined changes in indifference points when rats were making choices between one or two pellets as compared to choices between three or six pellets. Group mean indifference points were lower when subjects made choices between three and six pellets suggesting decreased self-control with increased absolute size of reinforcers even though the reinforcer ratios were unchanged. This may account for some of the difference observed across experiments since research examining choice patterns of pigeons typically present pigeons with a choice between 2 s and 6 s of access to grain which may not be functionally equivalent to a choice between 1 and 3 pellets. This possibility is further supported by the findings of Tobin et al. (1993). Tobin et al. (1993) showed that rats would make impulsive choices when presented with a
choice between 2 s and 6 s of access to sweetened condensed milk. Future research examining discount curves using the fast-adjusting delay procedure with different reinforcer amounts but with similar ratios may provide important information concerning this account. Also, research examining the influence of increasing reinforcer amounts when the reinforcer is either food pellets or access to grain when either discretely presented or mass presented would also illuminate the influence of this procedural difference across experiments. For instance, the discrete presentation of portions of a large reinforcer may influence the impact of that reinforcer on preference. A rat may be presented with three pellets at 1 s intervals while a pigeon may be presented with three seconds of grain access via continuous feeder presentation. Such experiments would not only provide evidence about the influence of these procedural differences but also the way that these variables influence the discount functions, i.e., how the slope or y-intercept influenced.

Another and similar possibility is that the levels of deprivation may have been different in the current experiments than that used with pigeon subjects. This account is not supported by self-control choice research that has shown inconsistent effects of deprivation level on self-control choice. Several researchers have reported no effect (Logue, Chavarro, Rachlin, and Reeder 1988; Logue and Peña-Correal 1985), some reporting decreased self-control with increased deprivation (Eisenberger and Masterson 1987; Eisenberger et al. 1982; Snyderman 1983), and others reporting increased self-control (mean adjusting delays at indifference) with increased deprivation (Bradshaw and Szabadi 1992; 1993; Christensen-Szalanski, Goldberg, Anderson and Mitchell 1980; Ho et al. 1997; Wogar et al. 1992). Ho et al. (1997) demonstrated decreased y-intercepts
and increased slopes of the linear regression analysis comparisons between groups at 90% of their free feeding weight as compared to subjects at their 80% free feeding weight (Ho et al. 1997). Future studies are needed to determine the impact of different food restriction regimens on self-control choice using a rapid adjusting delay procedure.

The procedures used in Experiment 2 are of practical significance for researchers interested in examining delay discount functions because the procedures allow for rapid determination of the functions. The procedures proposed by Mazur (1987) examined indifference points by presenting one standard delay until stable indifference was established before presenting the remaining standard delays of the discount curve. The procedures used in Experiment 2 allowed for assessment of the discount curve within only a few months as compared to the more lengthy Mazur procedure. Rapid determination of the discount function makes possible the quantification of the influence of such variables as deprivation level, changes in amount of reinforcement, changes in post-reinforcer delays, etc. The findings from Experiment 2 have pragmatic significance by demonstrating the use of a more timely procedure for the examination of delay discount functions. This rapid procedure will be useful for future research interested in how reinforcement variables influence self-control choice.

In summary, the findings from the current experiment were consistent with previous research showing decreased preference for the large, delayed reinforcer of three pellets with increased delays as demonstrated by reversal of preference from almost 100% choices for the large, delayed reinforcer to near 0% choices for that reinforcer with increased delays. A modified version of the rapid adjusting amount procedure was used to obtain delays to three pellets at which preference was indifferent or equivalent across
the two alternatives. Linear regressions of the mean adjusting delay at indifference as a function of the standard delay produced positive slopes and y-intercepts consistent with previous experimental research and the hyperbolic discount model proposed by Mazur (1987). The rapid adjusting amount procedure was successfully extended to an adjusting delay arrangement to quickly produce discount functions in rats. The data produced across session variability and the variables responsible for this variability need further examination. The current findings were different from those previously reported in that rats made self-control choices under conditions typically producing impulsive choice in pigeons and the discount functions reported in Experiment 2 included higher y-intercepts than those typically demonstrated with pigeon subjects. These differences are likely to be the result of quantitative differences in the discount function relating reinforcer value as a function of delay. It is still unclear whether variables such as deprivation level or relative reinforcer value are responsible for these differences.
REFERENCES


BIOGRAPHICAL SKETCH

I completed my undergraduate training at Utah State University where I obtained a Bachelor of Science degree in psychology. I first became interested in behavior analysis at Utah State University as an undergraduate after a class in behavior analysis taught by Dr. Carl Cheney. My interests in behavior analysis were further shaped and cultivated under the tutelage of Dr. Carl Cheney and Dr. Frans van Haaren. I have worked with Dr. van Haaren at the University of Florida over the course of completing a Master of Science and Doctor of Philosophy degrees in psychology with a specialty in the Experimental Analysis of Behavior and Behavioral Pharmacology. Early in my graduate training, I began doing research designed to investigate how both pharmacological and non-pharmacological variables influence self-control choice in rats. An examination of the influence of several pharmacological variables on self-control choice was the main purpose of my thesis research. This research was extended in the course of completing my doctoral research by examining how increasing the delays to a self-control alternative influenced choices of rats. The course of this research was shaped by the guidance of all my committee members while in the Department of Psychology at the University of Florida.