May 2015

Examining the Constant Difference Effect in a Concurrent Chains Procedure

Carrie Suzanne Prentice
University of Wisconsin-Milwaukee

Recommended Citation

Prentice, Carrie Suzanne, "Examining the Constant Difference Effect in a Concurrent Chains Procedure" (2015). *Theses and Dissertations.* Paper 831.

EXAMINING THE CONSTANT DIFFERENCE EFFECT IN A CONCURRENT CHAINS PROCEDURE

by

Carrie S. Prentice

A Thesis Submitted in

Partial Fulfillment of the

Requirements for the Degree of

Master of Science

in Psychology

at

The University of Wisconsin-Milwaukee

May 2015

ABSTRACT
EXAMINING THE CONSTANT DIFFERENCE EFFECT IN A CONCURRENT CHAINS PROCEDURE

by

Carrie S. Prentice

The University of Wisconsin-Milwaukee, 2015
Under the Supervision of Professor John C. Moore

According to the constant difference effect (Savastano & Fantino, 1996), preference for the shorter link in a pair of terminal links should be the same as for the shorter link of another pair of terminal links, given that the absolute difference between the two terminal links is constant. Hyperbolic Delay Discounting (Mazur & Biondi, 2009; see also Mazur, 2002) asserts that preference for the shorter link should decrease hyperbolically. The current experiment examined these models using pigeons as subjects in a concurrent chains experiment, with equal initial links of VI 30 s and terminal links of VI 10 s vs VI 30 s, VI 30 s vs VI 50 s, and VI 50 s vs VI 70 s. Results supported the Hyperbolic Delay Discounting model.

TABLE OF CONTENTS

1. Title Page

2. Abstract……………………………………………………….ii

3. List of Figures………………………………………………...iv

4. List of Tables.…………………………………………...……..v

5. Introduction…………………………………………………... 1

6. Method……………………………………………………...……7

7. Results……………………………………………………….…..….9

8. Discussion……………………………………………………12

9. Figures……………………………………………………….16

10. Tables……...…………………………………………………18

11. References……………………………………………………21

LIST OF FIGURES

1. *Figure 1*…………………………………………………….…...……..16

   Choice proportions for the shorter terminal link in the VI 10 s vs VI 30 s condition, the VI 30 s vs VI 50 s condition, and the VI 50 s vs VI 70 s condition.

   a. *Panel 1.* Choice proportions for Pigeon 29
   b. *Panel 2*. Choice proportions for Pigeon 22

2. *Figure 2.* …………………………………………………………17

   Choice proportions for the shorter terminal link in the VI 10 s vs VI 30 s condition, the VI 30 s vs VI 50 s condition, and the VI 50 s vs VI 70 s condition.

   c. *Panel 1.* Choice proportions for Pigeon 48
   d. *Panel 2.* Average choice proportions for all three pigeons

LIST OF TABLES

1. Table 1. Results for Pigeon 29...…..……………………………18
2. Table 2. Results for Pigeon 22…………………………………..19
3. Table 3. Results for Pigeon 48……………….……….………………20

Developed by Autor (1960), the concurrent chains procedure is often used in behavioral research, usually involving rats or pigeons. In this procedure, two chain schedules of reinforcement are presented concurrently. Each chain is comprised of an initial and a terminal link. The initial links of the chains are simultaneously available. In pigeon research, each initial link is represented by a lighted key. When a key peck has satisfied an initial-link schedule, the corresponding terminal link is activated. When a key peck has satisfied the terminal-link schedule, the pigeon receives a reinforcer, following which both initial links are reinstated. In much concurrent chains research, the initial links of both chains use identical schedules. The independent variable is therefore the difference between the terminal link schedules. The dependent variable is the choice proportion, calculated by dividing the number of pecks on one initial link key by the number of pecks on both initial link keys. In this way, we can determine how much each terminal link is preferred by a mathematical percentage.

Several models have been developed to describe choice behavior. The present experiment contrasts the effectiveness of models of choice behavior that can be applied to concurrent chains procedures. The first model, developed by Fantino (1969), is based on “Delay Reduction Theory” (DRT). DRT holds that “the effectiveness of a stimulus as a conditioned reinforcer may be predicted most accurately by the reduction in time to primary reinforcement correlated with its onset, compared to the average overall time to primary reinforcement” (Savastano & Fantino, 1996, p. 97). In order to express this relation mathematically, Squires and Fantino (1971) developed an equation intended to predict preferences in concurrent chains experiments:

$$\frac{R_L}{R_L + R_R} = \frac{T - t_{2L}}{(T - t_{2L}) + (T - t_{2R})}$$

In this equation, R_L and R_R are the number of initial-link responses on the left and right side keys, and t_{2L} and t_{2R} are the left and right terminal-link durations. Squires and Fantino (1971, p. 28) calculate T as follows:

First, the expected time to reach a terminal link from the onset of the initial link is:

$$\frac{1}{{}^{1}/_{t_{1L}} + {}^{1}/_{t_{1R}}}$$

where t_{1L} and t_{lR} are the average durations of the left and right initial links, respectively. Then, the average time to reinforcement after the onset of a terminal link is:

$$\mathbf{pt_{2R} + (1 - p)t_{2L}}$$

where p and (1-p) represent the probability of entering the right and left terminal links, respectively, and where $p = t_{1L}/(t_{1L} + t_{1R})$. From these values, the full expression is:

$$\mathbf{T} = \frac{1}{\mathbf{1/t_{1L} + 1/t_{1R}}} + \mathbf{pt_{2R} + (1 - p)t_{2L}}$$

This equation implies a relation known as the "constant difference effect". The constant difference effect holds that the preference shown for the shorter terminal link in a pair should be the same as the preference for any other shorter terminal link, as long as the absolute difference between the shorter and longer links in each pair is held constant. For example, the preference shown for a VI 10 s link over a VI 30 s link should be the same as the preference shown for a link of VI 50 s over a link of VI 70 s, because the absolute difference between the shorter and longer links in each pair is 20 s.

Although the validity of DRT regarding the constant difference effect has been explored through various studies, the results of this research have been inconclusive. Savastano and Fantino (1996) conducted a study which seems to support DRT. They implemented a concurrent chains procedure that used equal initial links, and varying terminal links; the absolute difference between terminal links was held constant at 20s. Even though the ratio between terminal links differed from one condition to another, the pigeons' choice proportions remained roughly equal across conditions despite the change in ratio. This finding supports the conclusion that terminal link preference is a function of the absolute difference between terminal links, and not a function of the ratio.

Challenging Savastano and Fantino's findings, Mazur (2002) used a concurrent chains procedure with equal VI 30s initial links, and varying durations of VT terminal links. Terminal link durations were either VT 2s vs VT 12s or VT 40s vs VT 50s, thus maintaining a constant difference of 10s between terminal links. Results showed preference for the shorter link decreased when the duration of both terminal links increased, inconsistent with a constant difference effect.

Further refutation of the constant difference effect can be found in research on delay discounting. Building on the foundation of Weber's Law, in which discrimination depends on the relative, not absolute difference between two stimuli, delay discounting focuses on the relative delays to reinforcement. Preference is shown more strongly for links that signal a shorter delay to reinforcement. However, as two links increase in absolute duration, it becomes more difficult to distinguish between them; therefore we expect preference to converge on indifference as the absolute duration of both links increases, but the relative difference decreases. This expectation follows from a hyperbolic decay function:

$$\mathbf{V = A \div [1 + KD]}$$

In this formula, V represents the value or strength of the reinforcer, A represents the amount of the reinforcer, D is the delay from the response to the reinforcer, and K describes the inverse relationship between K and D. Following Mazur (1986), we assume that K=1. This equation does not provide us with an expected absolute value to evaluate preference. Rather, the values found by this equation are to be seen in relation to one another, and provide an expected pattern of preference. Preference for the shorter link should decrease as the absolute durations of terminal-link pairs increase. However, that decreasing preference should not be linear. Instead, data that conform with hyperbolic discounting should follow a hyperbolic curve. We should see the greatest decrease in preference between terminal-link pairs that are relatively short, and a more gradual decrease in preference as durations increase.

To express this function in terms of a concurrent chains procedure, we can modify the formula to reflect the value of the stimulus as a proportion between left and right keys:

$$\frac{\mathbf{R_L}}{\mathbf{R_L+R_R}} = \frac{\mathbf{V_L}}{\mathbf{V_L+V_R}}$$

In a study that examined delay discounting, Mazur and Biondi (2009) manipulated time delays to reinforcement and amount of reinforcers, with an unchanging standard alternative on one key and an adjusting alternative on the other key. The number of reinforcers in the various conditions were one vs. two, one vs. three, and two vs. three. The duration of the adjusting alternative was titrated during a session to create indifference (equal choice) between the two keys.

Mazur and Biondi (2009) found that key preferences were described by the hyperbolic decay function. The fact that their results are described by a hyperbolic function suggests that a 10 second difference between schedules may only be behaviorally significant when the absolute duration of the two schedules is fairly short. When the absolute duration of the schedules is long, the behavioral significance of a 10 second difference diminishes.

In addition, in a study using both pigeons and rats as subjects, Green and colleagues (2004) utilized an adjusting amount procedure in which the delays varied from 1 s to 32 s. They found a hyperbolic function describing the decreasing value of reinforcement as time to reinforcement increased. This result is in keeping with numerous delay discounting experiments using humans (e.g., Dixon, Jacobs, & Sanders, 2006; Green, Fry, & Meyerson, 1994; Kirby, 1997; Rachlin, Raineri, & Cross, 1991), which support hyperbolic discounting, and also argue against a constant difference effect.

Worth noting is that although there is evidence in the literature that challenges it, Fantino’s research is not alone in suggesting a constant difference effect. Grace’s (1996) Contextual Choice Model (CCM) also makes similar predictions. Essentially, CCM explains the outcome of concurrent chains research as an extension of the Matching Law. The Matching Law holds that responses on an initial link reflect the value of the terminal link. CCM expands on this, positing that the value of the terminal link can be influenced my multiple factors. Grace asserts that “the value of a terminal link stimulus as a conditioned reinforcer is determined by the average delay to reinforcement (i.e., rate) in its presence” (p. 119), but also that that terminal-link sensitivity depends on the temporal context, which takes both initial link and terminal link schedules into consideration. According to CCM, the preference for a terminal link is controlled by two opposing forces; as the immediacy of the reinforcer declines, the temporal context increases the effectiveness of the terminal links.

Therefore, although CCM predicts that preference for a shorter terminal link should remain equal across various conditions, the degree of that preference is controlled by more than just the absolute difference between two terminal links. Additionally, this model differs from DRT by separating the conditioned reinforcement value from the effectiveness of the differences between stimuli. In this way, CCM can explore stimulus parameters other than delay, such as magnitude. The delay-reduction hypothesis is unable to do this, as DRT focuses solely on temporal delay.

Previous studies using concurrent chains have investigated such variables as the amount of reinforcement, the latency between response and reinforcement, the length of initial links, and the length of terminal links. Many studies previously discussed have manipulated several of these variables at once, and results from these studies have been mixed. The current study examined the constant difference effect using an absolute difference of 20 seconds between terminal links (e.g., Savastano & Fantino, 1996). The initial links were always VI 30 s, and the terminal links explored were VI 10 s vs. VI 30 s, VI 30 s vs. VI 50 s, and VI 50s vs. VI 70s. This design, while simple, allows for more a more thorough exploration of a single variable, and more precise interpretation of the results.

Method

Subjects

The subjects were three pigeons: Pigeon 29, Pigeon 22, and Pigeon 48. The three pigeons were of mixed breeds, varying ages, and varying experimental histories. Two pigeons were female, and one was male. Each pigeon was kept at approximately 80% of its free-feeding weight for the duration of the study. During the study, the pigeons had free access to water and grit in their home cages, and the vivarium light cycle was 16-hours-on, 8-hours-off.

Apparatus

Two operant chambers were used. When closed, both chambers were designed to block all outside light, and included an integrated ventilation fan system that masked background noise. The chambers contained an intelligence panel with three circular pecking keys, 2.5 cm in diameter, spaced evenly at 23.5 cm above the chamber floor. The keys illuminated by white, red, and green 28v DC lights. Only the side keys were used in the present experiment; the center key was dark and inoperative throughout. The food hopper was 5cm by 6cm, centrally located in the intelligence panel, 2.5cm above the chamber floor.

Procedure

This experiment utilized the concurrent chains procedure. As described in Briggs (2010) the procedure is a concurrent schedule of reinforcement wherein the initial links of two chain schedules are in effect simultaneously. With pigeons, each initial link of the two chains is associated with one of the two side keys in the operant chamber. After an initial link is completed with a key peck, the chain will advance to that chain's corresponding terminal link. After the terminal link is completed with a key peck, the pigeon receives three seconds of food reinforcement, and the cycle repeats.

The chains in this experiment consisted of equal initial links of VI 30s, and a pair of terminal links. The first pair of terminal links was VI 10s vs. VI 30s, the second pair VI 30s vs. VI 50s, and the third pair VI 50s vs. VI 70s. The shorter of the two terminal links was associated with either the left key or the right key of the operant chamber for each condition. Each pigeon was trained on each of the three terminal-link conditions, as well as the reversal for that condition, in order to demonstrate experimental control.

After completion of a terminal link, the pigeon was given three seconds of access to food as the reinforcer. Sessions were approximately 40 minutes in length. To accommodate this time limit, the number of reinforcers per session was different for each terminal link pair. There were approximately 62 reinforcers per session for the VI 10s vs. VI 30s terminal-link condition, 52 reinforcers for the VI 30s vs. VI 50s terminal-link condition, and 42 reinforcers for the VI 50s vs. VI 70s terminal-link condition.

After the initial exposure to a pair of terminal-link schedules, the pigeons were trained in a condition with non-differential terminal links (e.g., VI 10s vs. VI 10s) for 5 to 10 sessions. This condition facilitated the reversals by bringing the pigeons back to approximately equal responding across both left and right keys during the initial links.

The dependent measure was the pigeons' choice proportion, which is the extent to which each pigeon prefers one chain to the other. This choice proportion is calculated by using a formula of L/L+R, where L is the number of responses on the initial link of the chain associated with the left key, and R is the number of responses on the initial link of the chain associated with the right key.

Each condition was terminated once it reached stability or 30 sessions, whichever came first. Stability was calculated starting at session 15. To calculate stability, the choice proportions for the last nine sessions were divided into three blocks of three sessions each. The averages of each of these three blocks was used to determine if a pigeon's behavior had reached stability. Behavior was judged stable when two conditions were satisfied. First, the choice proportions of each block could not be monotonically increasing or decreasing. Second, the choice proportions had to be within .05 of each other. When those two conditions were satisfied, the pigeons were advanced to the non-differential condition, and then on to the next experimental condition. Tables 1-3 list the experimental conditions and their reversals in the order in which they were conducted.

Results

The number of sessions needed per condition to reach stability ranged from a minimum of 15 sessions to a maximum of 30. The analysis was based on the nine stable sessions, or the last nine sessions if the maximum of 30 sessions was reached. The maximum was reached in only one condition, which was the third determination of the VI 30 s vs. VI 50 s condition for Pigeon 29.

Figure 1 displays the pigeons' choice proportions for each determination as a function of the shorter terminal link in each condition. The Figures also display a mean line of all determinations for each condition. The mean lines in the panels representing the individual pigeons primarily represent the averages of only two determinations, the initial and reversal for each condition. The VI 30 s vs. VI 50 s conditions for all three pigeons, and the VI 50 s vs. VI 70 s condition for Pigeon 48 are the exceptions, and represent the averages of three determinations. In these cases, the difference between the initial and reversal determinations was excessive. To rule out a possible positional bias, a third determination was conducted, to mitigate against interpretation that could reflect an extraneous influence. Therefore, for all three pigeons there are three data points represented in the figures for the VI 30 s vs. VI 50 s condition. The data for Pigeon 48 also shows three data points for the VI 50 s vs. VI 70 s condition. Panel 2 in Figure 2 shows the average choice proportion for each pigeon for each of the three conditions. Each pigeon's data is represented by a different symbol, and the mean line represents the data as averaged across the three pigeons.

Ideally, if the data supported a constant difference effect, the preference for the shorter terminal link would remain the same across all three pairs of terminal links. This would be seen in the figures as a horizontal line connecting the three conditions.

Figures 1 and 2 display a pattern of responding that decreases as the ratio between the two terminal links in each condition decreases. All three pigeons show a stronger preference for the shorter link in the VI 10s vs. VI 30s condition, and a weaker preference for the shorter link in the VI 50s vs. VI 70s condition. This can be seen especially well in Panel 2 of Figure 2, which displays the averages of the data from all three pigeons.

Pigeon 29 shows a stronger choice proportion for the VI 10s vs. VI 30s, of 65%. This choice proportion then decreases to 57% or the VI 30s vs. VI 50s condition. For the VI 50s vs. VI 70s condition, the choice proportion decreases to 53%. Pigeon 22 shows a choice proportion of around 72% for the VI 10s vs. VI 30s condition. This preference remains stable at 72% for the VI 30s vs. VI 50s condition. For the VI 50s vs. VI 70s condition, the choice proportion decreases to 56%. Pigeon 48 also shows a stronger choice proportion for the VI 10s vs. VI 30s, of 86%. This choice proportion then decreases to 70% or the VI 30s vs. VI 50s condition. For the VI 50s vs. VI 70s condition, the choice proportion remains relatively stable at 69%.

Tables 1-3 provide complete data regarding these determinations. The conditions in each table are listed in the order in which they were conducted. Listed are the schedules for the chains with initial links and terminal links, the response per minute of the initial links, the response per minute of the terminal links, the terminal link inter-reinforcement interval, the number of sessions needed to reach stability, and the choice proportion, for each condition. Each row represents data for one determination, with data for both left and right key chains shown in one row. The responses per minute on the terminal link keys were as expected. The terminal link inter-reinforcement-interval is used as a reliability measure, to ensure that an approximate 20 second difference was maintained throughout the experiment. The number of sessions needed to reach stability, and the choice proportion for each determination are also included in the Tables.

As seen in Table 1, for VI 30 s vs. VI 50 s, the third determination for Pigeon 29 was 73%, which is more in keeping with its earlier data point of 58% in the initial determination. As seen in Table 2, the third determination for Pigeon 22 was 83%, in keeping with its earlier data point of 87% in the reversal determination. As seen in Table 3, the third determination for Pigeon 48 was 84%, which is more in keeping with its earlier data point of 72% in the initial determination of the VI 30 s vs. VI 50 s condition. For the VI 50 s vs. VI 70 s condition, the third determination for Pigeon 48 was 77%, in keeping with its earlier data point of 76% in the initial determination. Consistent with conventional practice, the data for these conditions were averaged across all three determinations to increase the validity of the overall interpretation of the data. These data are presented graphically in Figures 1 and 2. These data support hyperbolic discounting, which holds there should be decreasing preference for the shorter link as the absolute duration of the links increase.

Discussion

The present experiment examined the Delay Reduction Theory (DRT) and the Hyperbolic Decay Model, using a concurrent chains procedure where the absolute difference between each terminal-link pair was 20 s. If the data supported a constant difference effect, the preference for the shorter of the two terminal links in each condition would remain constant across all conditions. If the data supported the Hyperbolic Decay Model, ideally preference would decrease monotonically as the absolute duration of the terminal link pairs increase.

For Pigeons 29 and 48, support for Hyperbolic Decay is clear. Pigeon 29's data show the highest choice proportion in the VI 10 s vs. VI 30 s condition, with preference decreasing from the VI 30 s vs. VI 50 s condition to the VI 50 s vs. VI 70 s condition. The data for Pigeon 48 shows that preference decreases from the VI 10 s vs. VI 30 s condition to the VI 30 s vs. VI 50 s condition, and then again—although the decrease is less—from the VI 30 s vs. VI 50 s condition to the VI 50 s vs. VI 70 s condition. Pigeon 22, on the other hand, shows a different pattern of decreasing choice proportion. The choice proportion for Pigeon 22 remains at around 71% for both the VI 10 s vs. VI 30 s condition and the VI 30 s vs. VI 50 s condition, with preference only decreasing from the VI 30 s vs. VI 50 s condition to the VI 50 s vs. VI 70 s condition.

Although one might assume that the pattern of responding for Pigeons 22 might favor a constant difference effect, for this to be the case, preference would have to remain consistent across all three conditions. Following the equation proposed by Squires and Fantino (1971), the choice proportion for all three conditions should be around 83%. The fact that there is decreasing preference seen in all three birds is more in keeping with Mazur (2002), and Mazur and Biondi's (2009) findings. Following the equation used by Mazur and Biondi, we should see a 31% decrease in preference between the VI 10 s vs. VI 30 s condition and the VI 30 s vs. VI 50 s condition, and a 17% drop in preference between the VI 30 s vs. VI 0 s condition and the VI 50 s vs. VI 70 s condition.

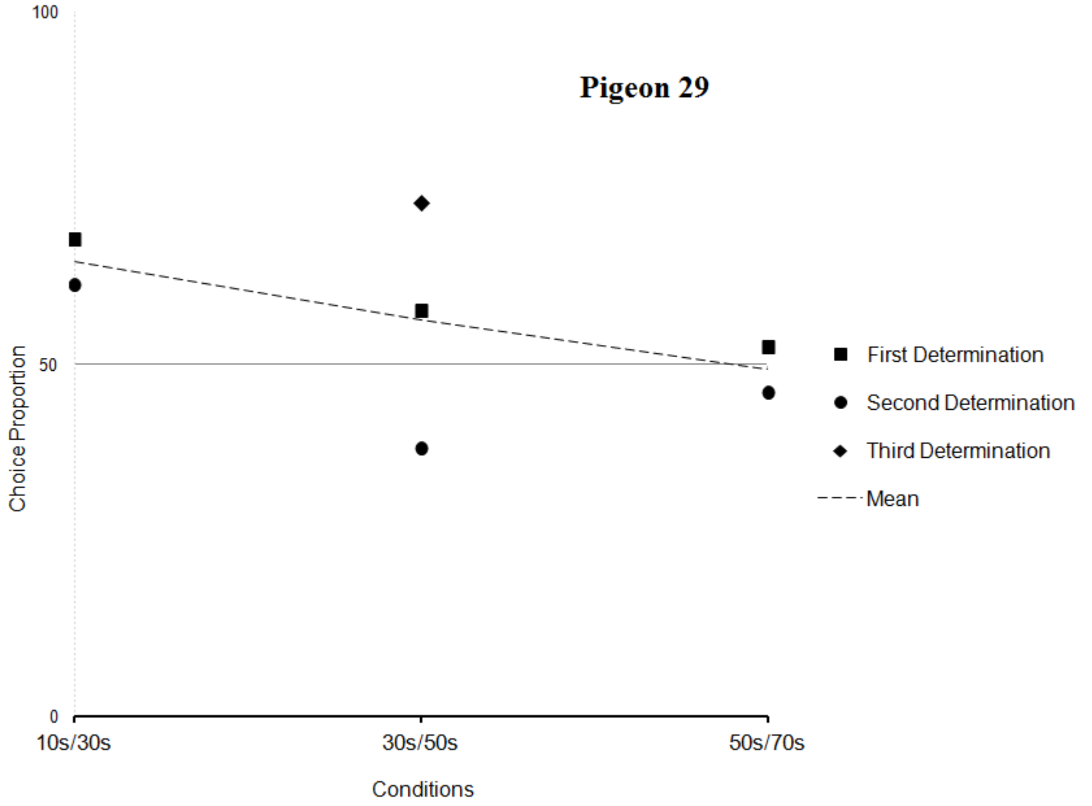
Although none of the pigeons follow this pattern exactly, both Pigeon 29 and Pigeon 48 show a greater decrease in preference from the VI 10 s vs. VI 30 s condition to the VI 30 s vs. VI 50 s condition than from the VI 30 s vs. VI 50 s condition to the VI 50 s vs. VI 70 s condition. It is unclear why Pigeon 22 had a relatively equal preference for the shorter link in both the VI 10 s vs. VI 30 s condition and the VI 30 s vs. VI 50 s condition. Ultimately, however, these data are more in keeping with Hyperbolic Decay, as preference does not remain stable across all three conditions.

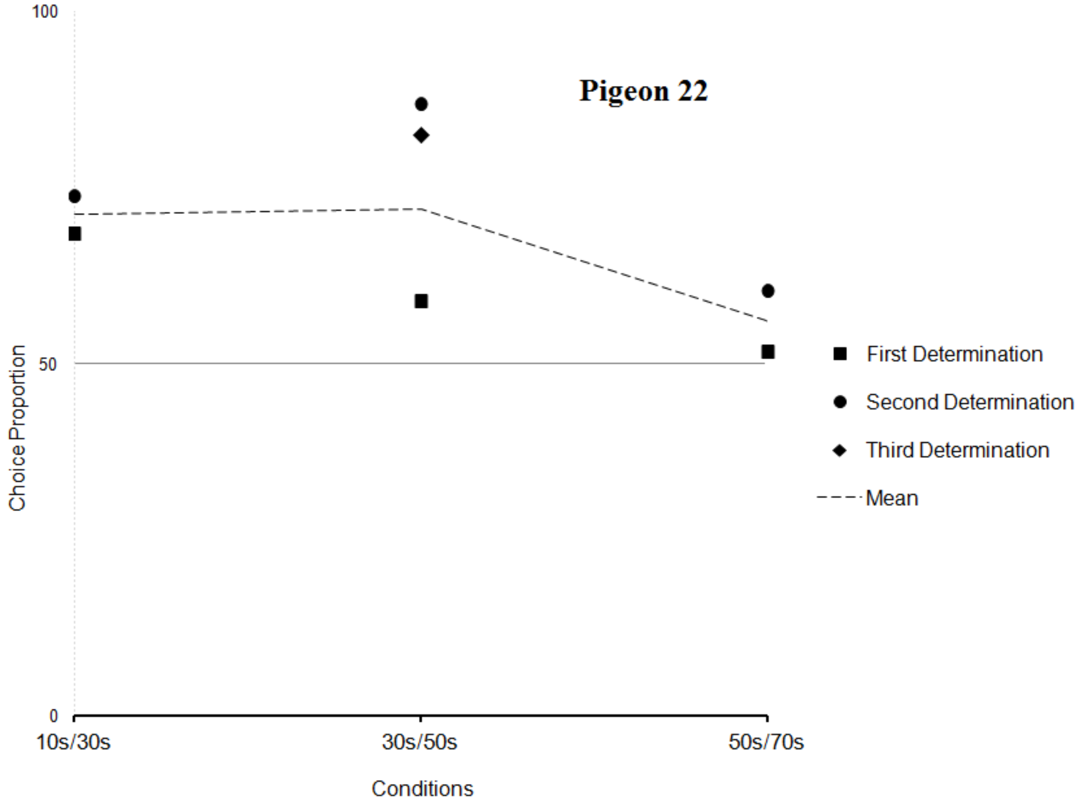
However, none of these data are completely unequivocal. All three birds had inconsistent reversals in the VI 30 s vs. VI 50 s condition. Through testing, we ruled out machine failures such as force and lighting differences between the left and right keys. Although each pigeon had its own small positional bias, this was controlled for by using the reversal conditions. It should also be noted that only Pigeon 48 had two such inconsistent reversals, and none of the pigeons had such results in the VI 10 s vs. VI 30 s condition. Although this could be due to the immediacy of the reinforcers allowing for better discrimination, if this were the case, it would follow that we should then see inconsistent reversals in the VI 50 s vs. VI 70 s condition as well, which is only the case for Pigeon 48. The reason for the extreme shift in bias for all three birds in the VI 30 s vs. VI 50 s condition is therefore unclear.

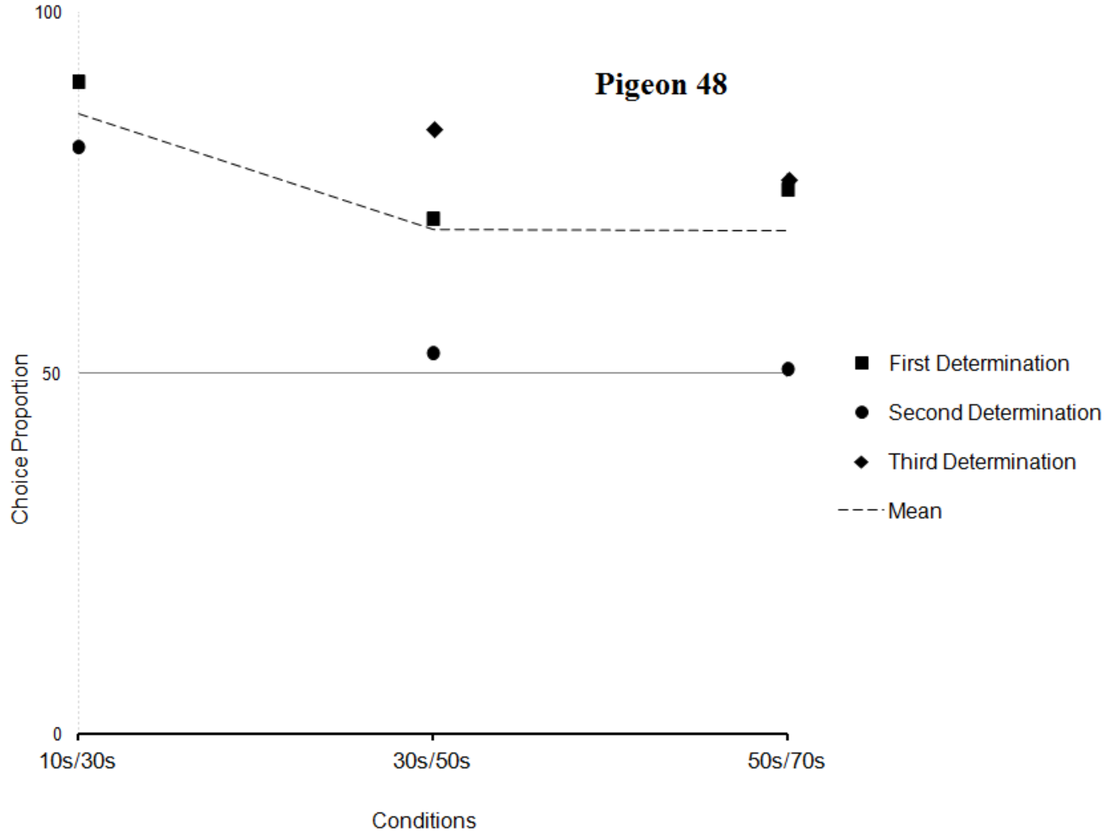
However, taken as a whole, these data ultimately support the Hyperbolic Decay Model over Delay Reduction Theory and Fantino’s constant difference effect. The present data confirm and extend those findings from 10s in Mazur’s experiments to a 20s difference. Savastano and Fantino (1996) also used a 20s difference, but their results supported a constant difference effect. It is unclear why Savastano and Fantino’s results are inconsistent with the bulk of other data on the topic. Mazur (2002) speculated that there were certain limitations to Savastano and Fantino’s research, noting procedural differences between their study and Mazur’s own research. Specifically, Savastano and Fantino used VI links, whereas Mazur used FT and VT links. Given that the present experiment not only uses a 20s difference, but also uses VI links, the reason for Savastano and Fantino’s results are rendered even more unclear.

However, to provide more definitive support for Mazur’s findings, several things could be done in future research. Firstly, more conditions can be added, which may render a more complete picture of hyperbolic responding. Secondly, four determinations can be run for each condition, which would more strongly rule out positional biases.

In conclusion, the present research has used a concurrent chains procedure to examine the Delay Reduction Theory (DRT) and the Hyperbolic Decay Model. If data supported DRT, it would have remained constant across all three conditions. The current data, show that preference decreased as terminal link durations increased, thereby supporting the Hyperbolic Decay Model.


Pigeon 29
100
50
0
Choice Proportion
10s/30s
30s/50s
50s/70s
Conditions
■ First Determination
● Second Determination
◆ Third Determination
Mean


Pigeon 22
100
50
0
Choice Proportion
10s/30s
30s/50s
50s/70s
Conditions
■ First Determination
● Second Determination
◆ Third Determination
Mean


Pigeon 48
100
50
0
Choice Proportion
10s/30s
30s/50s
50s/70s
Conditions
■ First Determination
● Second Determination
◆ Third Determination
Mean

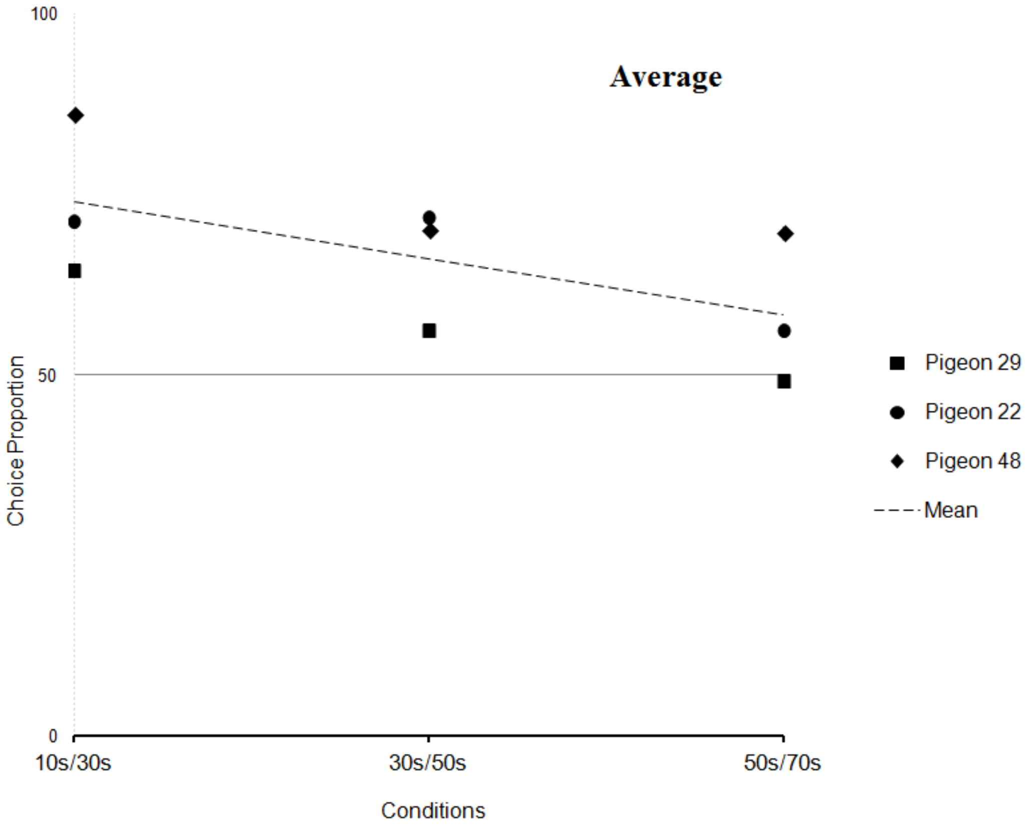

Average
100
50
0
Choice Proportion
10s/30s
30s/50s
50s/70s
Conditions
■ Pigeon 29
● Pigeon 22
◆ Pigeon 48
Mean

Table 1. Results for Pigeon 29

Condition	Schedule	Resp/min: Initial link	Resp/min: Terminal link	Terminal link IRI	Number of sessions	Choice proportion
1	L: Chain VI 30s VI 10s R: Chain VI 30s VI 30s	88 43	98 108	10 28	30	0.678
2	L: Chain VI 30s VI 30s R: Chain VI 30s VI 10s	60 78	115 153	28 10	29	0.614
3	L: Chain VI 30s VI 30s R: Chain VI 30s VI 50s	76 62	101 127	29 48	24	0.577
4	L: Chain VI 30s VI 50s R: Chain VI 30s VI 30s	75 52	103 114	49 29	26	0.381
5	L: Chain VI 30s VI 50s R: Chain VI 30s VI 70s	67 60	107 113	48 68	26	0.525
6	L: Chain VI 30s VI 70s R: Chain VI 30s VI 50s	59 48	127 130	67 48	19	0.461
7*	L: Chain VI 30s VI 50s R: Chain VI 30s VI 30s	38 67	94 143	50 32	30	0.729

* Third determination

Table 2. Results for Pigeon 22

Condition	Schedule	Resp/min: Initial link	Resp/min: Terminal link	Terminal link IRI	Number of sessions	Choice proportion
1	L: Chain VI 30s VI 30s R: Chain VI 30s VI 50s	27 22	75 68	29 49	24	0.591
2	L: Chain VI 30s VI 50s R: Chain VI 30s VI 30s	11 38	50 104	50 28	26	0.871
3	L: Chain VI 30s VI 10s R: Chain VI 30s VI 30s	34 18	114 106	12 28	25	0.686
4	L: Chain VI 30s VI 30s R: Chain VI 30s VI 10s	13 35	81 200	29 11	26	0.740
5	L: Chain VI 30s VI 50s R: Chain VI 30s VI 70s	28 28	79 76	48 68	27	0.518
6	L: Chain VI 30s VI 70s R: Chain VI 30s VI 50s	20 28	50 79	70 48	20	0.605
7*	L: Chain VI 30s VI 50s R: Chain VI 30s VI 30s	8 26	62 53	50 31	23	0.826

* Third determination

Table 3. Results for Pigeon 48

Condition	Schedule	Resp/min: Initial link	Resp/min: Terminal link	Terminal link IRI	Number of sessions	Choice proportion
1	L: Chain VI 30s VI 50s R: Chain VI 30s VI 70s	40 16	37 31	54 71	25	0.756
2	L: Chain VI 30s VI 70s R: Chain VI 30s VI 50s	26 24	45 39	72 52	29	0.507
3	L: Chain VI 30s VI 30s R: Chain VI 30s VI 50s	32 15	39 33	31 52	28	0.716
4	L: Chain VI 30s VI 50s R: Chain VI 30s VI 30s	21 24	37 35	51 31	25	0.530
5	L: Chain VI 30s VI 30s R: Chain VI 30s VI 10s	8 52	41 57	32 11	27	0.906
6	L: Chain VI 30s VI 10s R: Chain VI 30s VI 30s	42 12	38 42	12 32	27	0.815
7*	L: Chain VI 30s VI 70s R: Chain VI 30s VI 50s	15 40	16 30	72 50	22	0.769
8*	L: Chain VI 30s VI 50s R: Chain VI 30s VI 30s	13 39	19 36	50 31	22	0.839

* Third determination

References

Autor, S. M. (1960). *The strength of conditioned reinforcers as a function of frequency and probability of reinforcement.* Unpublished doctoral dissertation, Harvard University.

Dixon, M. R., Jacobs, E. A., & Sanders, S. (2006). Contextual control of delay discounting by pathological gamblers. *Journal of Applied Behavior Analysis, 39,* 413-422.

Grace, R. C. (1996). A contextual model of concurrent-chains choice. *Journal of the Experimental Analysis of Behavior, 61,* 113-129.

Green, L., Fry, A. F., & Myerson, J. (1994). Discounting of delayed rewards: A life-span comparison. *Psychological Science, 5,* 33-36.

Green, L., Myerson, J., Holt, D. D., Slevin, J. R., & Estle, S. J. (2004). Discounting of delayed food rewards in pigeons and rats: Is there a magnitude effect? *Journal of the Experimental Analysis of Behavior, 81,* 39-50.

Fantino, E. (1969). Choice and rate of reinforcement. *Journal of the Experimental Analysis of Behavior, 12,* 723-730.

Kirby, K. N. (1997). Bidding on the future: Evidence against normative discounting of delayed rewards. *Journal of Experimental Psychology: General, 126,* 54-70.

Mazur, J. E. (1986). Fixed and variable ratios and delays: Further tests of an equivalence Rule. *Journal of the Experimental Psychology: Animal Behavioral Processes, 12,* 116-124.

Mazur, J. E. (2002). Evidence against a constant-difference effect in concurrent-chains schedules. *Journal of the Experimental Analysis of Behavior, 77,* 147-155.

Mazur, J. E., & Biondi, D. R. (2009). Delay-amount tradeoffs in choices by pigeons and rats: Hyperbolic versus exponential discounting. *Journal of the Experimental Analysis of Behavior, 91*, 197-211.

Rachlin H., Raineri, A., & Cross, D. (1991). Subjective probability and delay. *Journal of the Experimental Analysis of Behavior, 55,* 233-244.

Savastano, H.I., & Fantino, E. (1996). Differences in delay, not ratios, control choice in concurrent chains. *Journal of the Experimental Analysis of Behavior, 66,* 97-116.

Skinner, B. F. (1953). *Science and human behavior:* New York: Macmillan.

Squires, N., & Fantino, E. (1971). A model for choice in simple concurrent and concurrent chains schedules. *Journal of the Experimental Analysis of Behavior, 15,* 27-38.