A Magnitude Effect in Temporal Discounting with Hens

A thesis

submitted in partial fulfilment

of the requirements for the degree

of

Masters of Applied Psychology in Behaviour Analysis

at

The University of Waikato

By

GRACE JOY BUDENBERG

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

2014

Abstract

This study aimed to determine whether a magnitude effect could be obtained in temporal discounting with brown shaver hens. Subjects responded in a classic self-control situation for the choice between a smaller-sooner reward (1-s access to food, after a 2 s delay) or a larger-later reward (4.5-s access to food, after a 28 s delay). Hens responded in a multiple concurrent-chain procedure on concurrent variable-interval (VI-30s, VI 30-s) schedules in the choice phase (initial links), and a fixed interval (FI) schedule, ranging from FI 2-s to FI 28-s in the outcome phase (terminal links). The outcome phase then resulted in reinforcement of either 1-s access to grain or 4.5-s access to grain. The results replicated the findings of a previous study by Grace, Sargisson & White (2012), who obtained evidence of a magnitude effect in temporal discounting with pigeons, in which subjects demonstrated a greater preference for the larger reward compared to the small reward over increasing time delay. The findings indicate that the magnitude effect is not unique to humans, as previous studies have suggested. Data was applied the Generalized Matching Law (GML) and the Contextual Choice Model (CCM) equations to determine if the data was comparable with models of behavioural choice.

Acknowledgments

First and foremost I wish to thank my supervisors, Dr. James McEwan and Associate Professor Lewis Bizo for their guidance and assistance throughout the process of planning and putting together this thesis. I also wish to thank Jenny Chandler, for writing my program, caring for the welfare of my hens and her positive attitude to problem solving. A special thank you must go to my fellow students at the Animal Behaviour and Welfare Research Unit. I know that without your support and teamwork that this thesis would not have been possible. I have learned so much from you girls.

To my family, Mum, Dad, Hannah and Lydia, I cannot express how important your unfailing encouragement and love has been in getting me to this point. I especially want to thank my Mum and Dad for never doubting in my ability to achieve my goals and for supporting me every step of the way. I would like to thank my constant companion Hugo, for always reminding me to look on the bright side of life and greeting me with smiles every day.

Finally, to my best friend and soon to be husband Scott, thank you for being my calming force and motivator throughout this journey. Your unwavering patience and belief in me, all while working long hours so that I could continue to study means everything. It's good to be on your team. I Love you.

Table of Contents

List of Figures

List of Tables

List of Appendices

Introduction

Self-control

Choices often involve a negotiation between the amount of reward and the delay to the receipt of that reward (Green & Myerson, 2004; Ong & White, 2004). The choice between rewards that vary in delay to the delivery of that reward can be examined from the perspective of temporal discounting, a widely studied aspect of intertemporal choice (Green & Myerson, 2004).

In temporal discounting, choice situations in which two alternatives differ in magnitude and delay to reinforcement, have been adopted under a framework of self-control (Bonem & Crossman, 1988; Green & Myerson, 2004; Rachlin & Green, 1972). Within this paradigm, the choice of the large reward at a longer delay is termed *self-control*, whereas the alternative choice of the smaller reward at a shorter delay is termed *impulsivity* (Green & Myerson, 2004; Grace & Hucks, 2013).

Researchers in this area have established that the value of a reward is generally discounted according to a hyperbolic function of time, in which the subjective value or effectiveness of a reward decreases, as the delay to receiving it increases (Grace & McLean, 2005; Green, Myerson, & McFadden, 1997; Green & Myerson, 2004). The hyperbolic model has been used to reliably describe rates of temporal discounting for both humans (Kirby, 1997; Myerson & Green, 1995; Rodriguez & Logue, 1988) and non-humans (Ainslie, 1981; Green & Estle, 2003; Green, Fisher, Perlow, & Sherman, 1981; Mazur, 1984). The functional similarity between humans and non-human has resulted in a large amount of research, mainly due to it's relevance for human decision making and applications to models of self-control (Beeby & White, 2013; Grace, 1999; Kinloch & White, 2013).

The results of studies with humans have demonstrated that larger rewards tend to be discounted at a lower rate over time compared to smaller rewards (Grace et al., 2012; Rapoport, Benzion, & Yagil, 1989). The effect of the amount of reinforcement on the rate of temporal discounting is known as the *magnitude effect* (Bonem & Crossman, 1988). The magnitude effect is a robust finding with humans and has been reliably obtained in studies in which participants have been asked to make choices between several types of reward outcomes, including money, health and personal relationships (e.g. Chapman, 1996; Johnson & Bickel, 2002; Tayler, Arantes, & Grace, 2009).

However, despite investigation with a variety of animal species and various types of rewards, the vast majority of studies with non-humans have so far failed to obtain any reliable magnitude effects (e.g. Calvert, Green, & Myerson, 2010; Grace, 1999; Green & Estle, 2003; Green & Myerson, 2004). Consistent evidence against a magnitude effect with non-humans has prompted some researchers to suggest that there may be a distinct difference in human and non-human temporal discounting (Calvert et al., 2010; Grace et al., 2012; Thaler, 1981).

Adjusting-amount procedures

Titration methods or adjusting-amount procedures have typically been used to study rates of temporal discounting and test for magnitude effects with humans participants (Holt, Green, & Myerson, 2012; Kinloch & White, 2013). This procedure was specifically designed to measure reinforcer ‘value’ by presenting subjects with the choice between a large-delayed (standard) reward, which is held constant or an immediate reward that adjusts in magnitude across trials. In adjusting-amount procedures, the adjusting alternative is increased in magnitude after the subject chooses the standard reward or successively decreased, after the subject chooses the adjusting alternative (Ong & White, 2004; Richards, Mitchell, de Wit, & Seiden, 1997).

The resulting series of discrete trial choices can then be used to measure the subject's *point of indifference*, which can be inferred when the standard and adjusting-amount alternatives are chosen with equal frequency and the subjective values are determined to be equivalent (Kinloch & White, 2013; Richards et al., 1997). In such procedures, the delay of the standard amount is manipulated across experimental conditions in order to examine the effect that delay has on the value of the standard reward (Ong & White, 2004; Richards et al., 1997).

The majority of temporal discounting studies with non-humans have also used adjusting-amount procedures (Grace et al., 2012; Kinloch & White, 2013). An example with non-humans can be seen in Experiment 3 of a study by Richards et al., (1997), who used an adjusting-amount procedure to determine whether different amounts of water would have an effect on temporal discounting rates for rats. The rats' indifference points for the standard amounts of water were established when it was determined that the amount of water available on the immediate alternative was equally preferred to the standard, delayed amount. The experiment included 15 conditions in which 3 standard amounts of water, 100 μl, 150 μl, and 200 μl were varied systematically over 0 s, 2 s, 4 s, 8 s and 16 s delays. Richards et al., (1997) found that the value of the standard amount decreased as the delay to reinforcement increased. The results showed no significant difference between the discounting rates for the small and large water rewards and thus, no evidence for a magnitude effect was obtained (Richards et al., 1997).

Green, Myerson, Holt, Slevin and Estle (2004) also used an adjusting-amount procedure to measure indifference points for rats and pigeons under various amount-delay combinations of food reward. Temporal discounting rates were examined for the amounts of 5, 12 and 20 pellets for rats and 5, 12, 20 and 32 pellets for pigeons over six delays, ranging from 1 s to 32 s (Green et al., 2004). The results indicated that the different amounts of reinforcement did not have a significant effect on discounting rates for the rats or pigeons (Green et al., 2004).

Freeman, Green, Myerson and Woolverton (2009) used an adjusting-amount procedure to examine rates of temporal discounting with rhesus monkeys. The subjects were presented with different amounts of 0.05% saccharin, either 4 ml or 2 ml, tested over delays ranging from 0 s to 60 s. Freeman et al. (2009) found that discounting rates for the monkeys were not affected by the amount of reinforcement available and no systematic magnitude effect was obtained (Freeman et al., 2009).

Calvert et al. (2010) conducted an adjusting-amount procedure to examine whether the quality of reinforcement would have an effect on temporal discounting rates for rats. The researchers tested both highly preferred and non-preferred liquid and food rewards in two experiments under various delays. The results indicated that the quality of reinforcement did not have a systematic effect on the temporal discounting rates for the rats (Calvert et al., 2010). The results from the studies outlined above are in clear contrast to the general findings of studies with human participants. The consistent evidence against a magnitude effect with non-humans responding under adjusting-amount procedures has prompted some researchers to investigate the magnitude effect in non-human temporal discounting using alternative procedures (Grace, 1999; Grace et al., 2012; Kinloch & White, 2013; Ong & White, 2004).

Concurrent-chain procedures

An alternative method to the adjusting-amount procedure is the concurrent-chain procedure, which has been widely used to study animal preferences and choice behaviour (Grace & Hucks 2013; Landon, Davison & Elliffe, 2003). Concurrent-chain procedures generally involve two signaled phases; a choice phase (initial-links), which provide access to one of two mutually exclusive reinforcement schedules in the outcome phase (terminal-link). In this type of procedure, subjects respond to two concurrently available variable interval (VI) schedules of reinforcement during the initial-links. Response allocation is then used to measure the relative value or effectiveness of the following terminal-link outcomes. Initial-links are then reinstated following reinforcer delivery in the terminal-link (Landon et al., 2003; Mazur, 2000; Grace & Hucks, 2013).

Concurrent-chain procedures may be used to examine rates of temporal discounting by inferring that the allocation of responses in the initial-links provide a measure of relative preference for the associated terminal-link reward, which is determined by the signaled delay to reinforcement (Grace & Hucks, 2013; Ong & White, 2004). In such procedures, a higher rate of responding in the initial-link related to the terminal-link providing a smaller, immediate reinforcer would be described as impulsivity. Alternatively, a higher rate of responding in the initial-link preceding the terminal-link with a larger, more delayed reinforcer would indicate self-control (Grace, 1999; Landon et al., 2003).

To date, few studies have used concurrent-chain procedures to test for a magnitude effect in the temporal discounting with non-humans (Kinloch & White, 2013). Grace (1999), first used a two-component concurrent-chain procedure to determine if amount of reinforcement would have an effect on temporal discounting rates with pigeons. In his experiment, Grace (1999) defined reinforcement magnitude as the duration of access to grain, which ranged from 1.6 s to 4.25 s. Reinforcement was either small or large in each trial and was maintained at a ratio of 2.5:1 between trials.

The initial-links of Grace's (1999) procedure were maintained on concurrent VI 30-s VI 30-s schedules across conditions and the terminal-links operated on independent VI schedules in both red and green components. Terminal link delay was varied systematically across conditions and functioned as the delay to reinforcement (Grace, 1999). The results provided no evidence of a magnitude effect, as there was no significant difference in the sensitivity to delay between large and small reinforcers (Grace, 1999). The study by Grace (1999) was later modified by Ong and White (2004), who argued that strong stimulus control of left versus right keys associated with different durations of terminal-link delays, may have masked the control of the red versus green trials, that signaled different reinforcement magnitudes in the terminal-links.

In order to test this, Ong and White (2004) reversed the terminal-link delays between trials. The researchers also arranged fixed interval (FI) schedules on the terminal-links, expanded the range of delay ratios and used non-independent scheduling in the initial-links of their procedure (Ong & White, 2004). The procedural changes were made in an attempt to enhance discriminability between the small and large reinforcement durations and ensure that the number of entries on the left and right keys were approximately equal (Ong & White, 2004).

Experiment 1 of Ong & White (2004) began with both keys illuminated either red or green in the initial-links, to signal different trials. Red and green trials were then alternated throughout the session. Initial-links operated on concurrent VI 30-s VI 30-s schedules that were non-independent in that, when the interval timer on one VI schedule timed out, the other also stopped. Terminal-links were signaled with either the left or right key illuminated white. Terminal-links operated under FI schedules, ranging from FI 2-s to FI 28-s across experimental conditions. The large reinforcer duration was 4.5-s for red trials and the small reinforcer was 1-s access to wheat for green trials (Ong & White, 2004).

The results of Ong & White (2004) did not show a reliable magnitude effect. Instead, the researchers found that sensitivity to delay was significantly greater for the large reward compared to the small reinforcer durations, indicating that the pigeons discounted the large reinforcer at a greater rate than the small reinforcer. These results were inconsistent with those of Grace (1999) and are the opposite of general findings for humans, who tend to discount larger rewards at a slower rate than smaller rewards over time (Ong & White, 2004).

In a later study, Grace et al., (2012) used a similar concurrent-chains procedure, although in contrast to the previous experiments by Grace (1991) and Ong and White (2004), the outcomes on each trial differed not only in delay but also in amount of reinforcement, which served to further enhance discriminability between the alternatives. This difference is notable as it consequently presented the subjects with a classic self-control situation; the choice between a larger-later or smaller-sooner alternative (Kinloch & White, 2013).

In their study, Grace et al., (2012) used a multiple concurrent-chains procedure to test for a magnitude effect with pigeons. The researchers examined temporal discounting functions by holding one delay constant and systematically manipulating the other. In their experiment, VI 30-s VI 30-s schedules were arranged non-independently and reinforcer magnitude was defined as duration of access to reinforcement. The smaller-sooner (SS) reinforcer was 1-s access to grain delayed by 2 s and the larger-later (LL) reinforcer was 4.5-s access to grain delayed by 28 s. The choice phase was signaled with both keys illuminated either red or green. In red trials the SS delay was held constant at FI 2-s and the LL delay was increased across conditions. During green trials, the LL delay was held constant at FI 28-s and the SS was successively increased (Grace et al., 2012).

Grace et al., (2012) found evidence of a significant amount-delay interaction. The results of the experiment show a significantly greater relative value for the large rewards compared to the corresponding small reward over the delays of 6 s, 15 s and 24 s. The difference for 28 s delay was not found to be significantly greater. Therefore, as opposed to previous studies, the results of Grace et al., (2012) provided evidence for a magnitude effect with pigeons.

Descriptive models of choice

After obtaining a reliable magnitude effect, Grace et al., (2012) applied the data from their experiment to two models of behavioural choice, The Generalized Matching Law (GML) and The Contextual Choice Model (CCM). The GML is well established as an effective quantitative model for describing allocation of choice behaviour (Davison & Baum, 2003; Grace & Hucks, 2013). The extended, concatenated version of the model enables the GML to be applied to a variety of choice situations including self-control, as it takes into account the variables of delay, amount and response bias in order to predict response allocation (Davison & Baum, 2003; Landon et al., 2003).

The CCM was proposed by Grace (1994) as an extension of the GML on the assertion that the temporal context of choice, the amount of time spent in the initial and terminal-links, has a significant effect on the sensitivity to delay and amount of reinforcement. According to the CCM, the sensitivity to delay and amount of reinforcement is heightened as the time spent in the terminal-link increases in relation to the initial-links (Grace, 1994; Grace et al., 2012).

By fitting the GML and the CCM equations to the average data, the researchers found that the CCM provided a better fit of the data with 91% of variance accounted for compared to the GML, which accounted for 78% of the variance (Grace et al., 2012). This is may be due to the fact that the CCM predicts a non-linear trend in the data in which the choice for the larger alternatives become more extreme as the overall durations are increased across successive experimental conditions (Grace et al., 2012).

Study aims and hypothesis

In their study with pigeons, Grace et al., (2012) obtained a magnitude effect in a classic self-control situation. These results differ from the general findings of previous temporal discounting studies with non-human animals. The novel nature of the results permits further investigation.

The aims of the present experiment were to replicate and extend the experiment of Grace et al., (2012) to another species and in doing so determine if a magnitude effect could be obtained with hens. Replication of the experiment by Grace et al., (2012) will also contribute to the small number of studies that have used concurrent-chains procedures as a method of examining the effects of reinforcement magnitude in temporal discounting with non-human animals.

It was hypothesised that the subjects would demonstrate a magnitude effect, in that they would show a higher preference for the choice phase associated with the LL outcome compared to the SS outcome, relative to the increasing delay in the outcome phase across successive conditions.

Method

Subjects

Six domestic brown shaver hens, *Gallus domesticus*, numbered 11 through to 16 were housed individually in wire cages (500-mm long x 510-mm wide x 420-mm high), in a ventilated room which was lit on a 12 hours light and 12 hours dark cycles. Hens were weighed daily and maintained at 85% ± 5% of their free-feeding body weight, which was maintained by post-session feeding of commercial pellets. Water and grit was made freely available and vitamin supplements were provided on a weekly basis. All subjects had previous experience on progressive ratio schedules of reinforcement and conditional discrimination procedures but not on concurrent-chains procedures.

Apparatus

An experimental chamber, which measured 615-mm long x 450-mm wide x 580-mm high was used. The interior was painted white with two operant response keys and a food magazine mounted on the right side of the chamber. The food magazine was located behind an opening and centred 105-mm above the floor. Two operant response keys (30-mm in diameter) were positioned 390-mm from the floor of the chamber and could be lit red, green or white. The keys required a force of approximately 0.2 N to be activated which was signaled by an audible beep. When activated, a light above the magazine was illuminated and the magazine was raised to allow access to wheat.

All experimental events were controlled and recorded from a computer running Med-PC IV software. The data at the end of each experimental session was manually recorded into a data book as well as being recorded by the computer software.

Procedure

A multiple concurrent-chains procedure, in which the subjects were repeatedly exposed to the same delay-amount combinations, was used. Each experimental session included two successive concurrent-chains components which began with both left and right response keys lit either red or green, This signaled the beginning of the choice phase (initial-links). Red and green trials were alternated throughout each session. During the choice phase, dependent concurrent variable-interval schedules averaging 30 s (VI 30-s) were arranged on left and right keys and responses were recorded. The VI duration on each key was randomly chosen from a list of 12 intervals.

When the VI schedule on one key timed out, timing also stopped on the other key. Access to the outcome phase (terminal links), was only possible via a response on the key associated with the timing out of the VI 30-s schedule. This arrangement allowed the events in the outcome phase to be experienced an equal number of times during each experimental session.

The key on which the outcome phase was entered, after the VI 30-s, elapsed, was lit white and the other key not lit. In the outcome phase, the first response after a fixed interval (FI) of time had elapsed on the lit key resulted in timed food delivery. Different FI schedules were arranged on left and right keys across five different conditions (see Table 1).

In both red and green trials, the first response to the left key after the FI schedule was completed resulted in 1-s of access to grain. The first response to the right key allowed subject’s 4.5-s access to grain. Following delivery of reinforcement, an intertrial interval (ITI) was chosen so that the interval from the beginning of the outcome phase to the start of the next choice phase was always 45 s.

Experimental conditions

The experimental sessions lasted for either 48 trials or a total of sixty minutes depending on which occurred first. Each hen completed one session daily when they were within their required weight range. Sessions were run seven days a week. The FI schedules were varied across five experimental conditions. In red trials, the FI schedule on the left was always held constant at FI-2 s and always resulted in 1-s of food delivery while the FI schedule on the right key increased successively from FI 2-s, FI 6-s, FI 15-s, FI 24-s and FI 28-s with each condition and resulted in 4.5-s access to food.

In green trials, the FI schedule on the right key was held constant throughout the five conditions on FI 28-s schedule for a 4.5-s access to grain. The FI schedule on the left key increased successively across conditions in the same pattern as the FI schedule operating on right key in red trials (FI 2-s, FI 6-s, FI 15-s, FI 24-s and FI 28-s) and resulted in 1-s access to food delivery via the magazine.

In Condition 1, the hens were exposed to baseline delay combinations in the outcome phase. On the red trials, a FI 2-s schedule operated on both left and right keys. If the outcome phase was entered on the left key, the hen would receive 1-s access to food after the FI 2-s schedule on that key had elapsed. If the outcome phase was entered on the right key, the hen would have access to 4.5-s of food delivery. The left key on the green trials operated on FI 2-s schedule, which resulted in 1-s of food delivery, and FI 28-s schedule on the right key which allowed 4.5-s access to food. Access to food was only available after the first response on the activated key after the specific FI schedule on that key had elapsed.

In Condition 2, the FI delay on the red trials remained at a FI 2-s on the left key resulting in 1-s access to food. The delay on the right key was increased to FI 6-s schedule followed by 4.5-s access to grain. The FI schedule on green trials remained at FI 28-s on the right key with 4.5-s access to reinforcement while the left key operated under a FI 6-s delay with 1 s reinforcement.

In Condition 3, the left key on red trials was held on a FI 2-s schedule and the right key was held on a FI 15-s delay. The right key on green trials remained on a FI 28-s schedule and the left key operated under a FI 15-s schedule of reinforcement. In Condition 4, the left key on the red trials was again held constant on a FI 2-s schedule, while the right key operated under a FI 24-s schedule. On green trials the right key remained on a FI 28-s schedule while the left key increased to a FI 24-s delay.

In Condition 5, the left key on red trials remained on a FI 2-s schedule while the right key operated on a FI 28-s schedule. On the green trials the right key was again, consistently held on a FI 28-s schedule, the left key also operated under a FI 28-s schedule of reinforcement. Each subject ran for a minimum of 25 days in each condition (see Table 2).

Data collection.

Data collection included the number of responses made to the left and right keys during the choice phase of each trial. Responses were recorded separately for red and green trials. Data was recorded on the proportion of responses to the left and right keys. The total session time, number of trials completed and reinforcers obtained on red and green trials per session were also recorded.

Table 1: Outcome phase schedules across conditions and reinforcer durations in red and green choice trials.

Condition	*Red*		*Green*	
	Left	*Right*	*Left*	*Right*
1	FI 2 s	FI 2 s	FI 2 s	FI28 s
2	FI 2 s	FI 6 s	FI 6 s	FI 28 s
3	FI 2 s	FI 15 s	FI 15 s	FI 28 s
4	FI 2 s	FI 24 s	FI 24 s	FI 28 s
5	FI 2 s	FI 28 s	FI 28 s	FI 28 s
Reinforcer Duration	1-s	4.5-s	1-s	4.5-s

Table 2. Number of days per condition for each subject.

Subject Number	*Hen 1.1*	*Hen 1.2*	*Hen 1.3*	*Hen 1.4*	*Hen 1.5*	*Hen 1.6*
Condition 1	42	29	30	41	41	40
Condition 2	38	27	25	34	36	31
Condition 3	25	27	25	26	25	25
Condition 4	27	29	34	32	33	25
Condition 5	49	31	50	42	45	41

Data Analysis

Generalised Matching Law and Contextual Choice Model equations

The GML predicts that response allocation in concurrent schedules can be determined by the following concatenated form of the GML equation (Baum & Rachlin, 1969; Grace & Hucks, 2013):

$$log\frac{B_L}{B_R} = a_D\, log\frac{1/D_R}{1/D_L} + a_M\, log\frac{A_L}{A_R} + logb, \qquad (1)$$

In Equation 1, *B* indicates responses, *D* indicates delay and *A* is the amount of reward available at the left and right alternatives. The GML includes three parameters, the sensitivity to delay (a_D), sensitivity to amount of reward (a_M) and response bias (*log b*). CCM is an extension of the GML as it takes into account the temporal context of choice (Grace, 1994):

$$log\frac{B_L}{B_R} = \frac{T_o}{T_c}\left[a_D\, log\frac{1/D_R}{1/D_L} + a_M\, log\frac{A_L}{A_R}\right] + logb, \qquad (2)$$

Equation 2 includes the addition of the exponents T_o and T_c which indicate the ratio of the average time spent in the outcome (T_O) and choice (T_C) phases of each trial in the concurrent-chains procedure (Grace, 1994; Grace & Hucks, 2013).

In the current study, Equations 1 and 2 are both are applied to the data. Response ratios made to left and right keys in each choice phase were averaged over the last five days of each condition, separately for red and green trials. The models were fit to the response ratios for individual animals using non-linear least squares regression. Table 2 and 3 show the respective parameter values calculated using the GML and CCM equations for each subject. Table 4 shows the parameter values calculated for data averaged across subjects for both the GML and CCM equations in red and green choice trials.

Results

Difference in relative preference between Red and Green choice trials.

Preference for the SS outcome relative to the LL outcome was measured as the logarithm of the ratio of responses to left and right keys in red and green choice trials in the concurrent chains procedure. The log response ratios varied across conditions as a function of the changing delay associated with the FI schedule, which was systematically increased across successive conditions (see Table 1). To show the variation in preference between red and green trials, a measure of the amount of difference between the log response ratios was calculated.

Figures 1, 2, 3, 4 and 5 show the difference in the log response ratios between red and green choice trials plotted for the first five and last five days in each condition. The filled data points represent the first five days and unfilled points represent the last five days of each condition. Figure 1 shows that for all subjects in Condition 1, the difference in relative preference between red and green choice trials significantly increased from the first five days to the last five days of the condition. Figure 2 shows a general decrease in the amount of difference between alternatives over the first and last five days in Condition 2 for the majority of subjects as the SS delay increased from 2-s to 6-s.

Figure 3 shows, that with the exception of Hen 1.2, there is little difference in preference between red and green alternatives in Condition 3 compared to the other four conditions. In Figure 4, the difference between red and green trials is shown to significantly increase again in Condition 4, which had a delay of 24-s for both LL and SS reward alternatives. Hen 1.1, Hen 1.3, Hen 1.4 and Hen 1.5 show the most significant increase in difference between alternatives in Condition 4. Figure 5 shows that the difference in log response ratios between

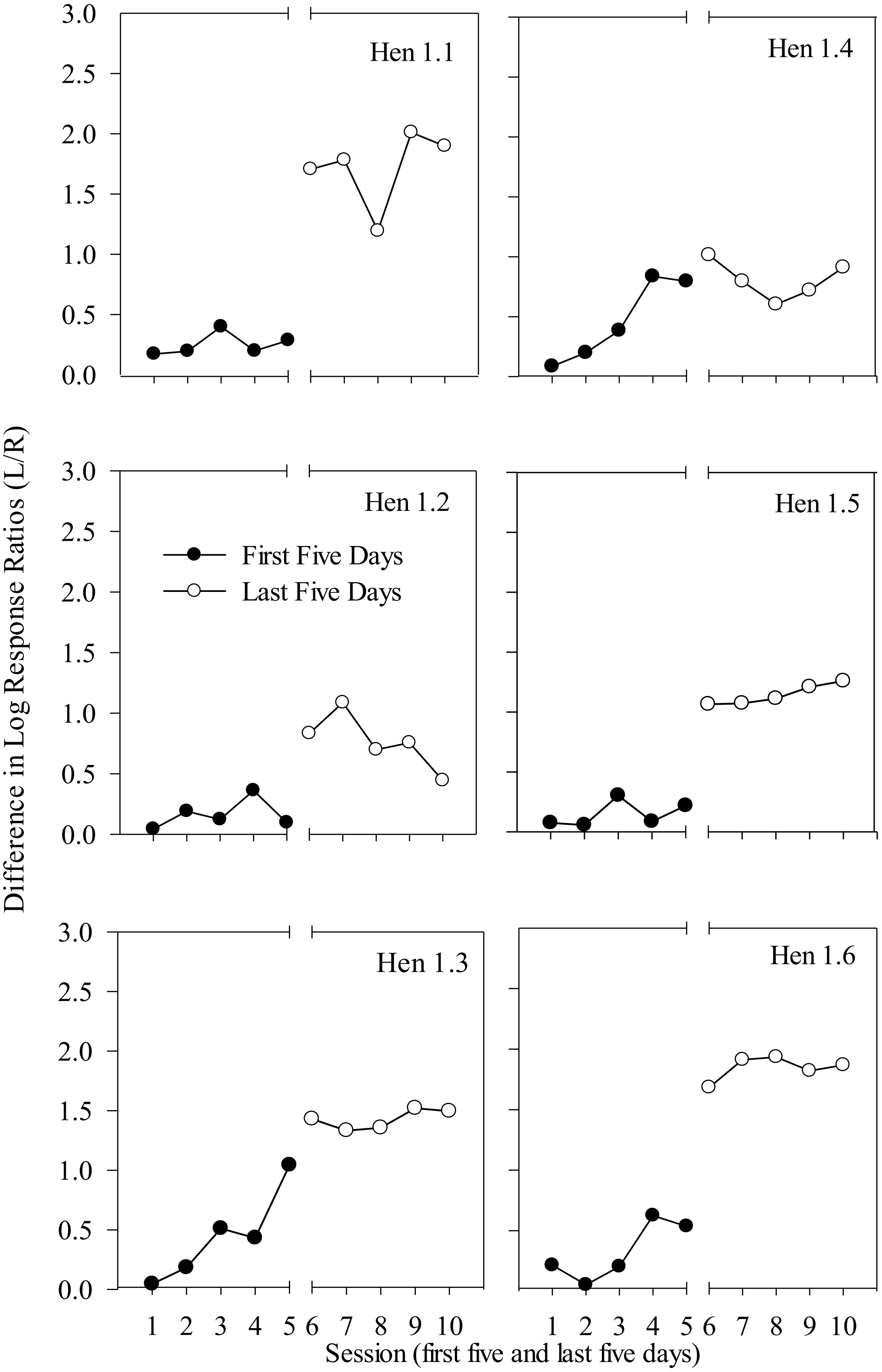

Figure 1: Difference in Log response ratios (Left/Right) between red and green trials for each subject in the first five and last five days in Condition 1.

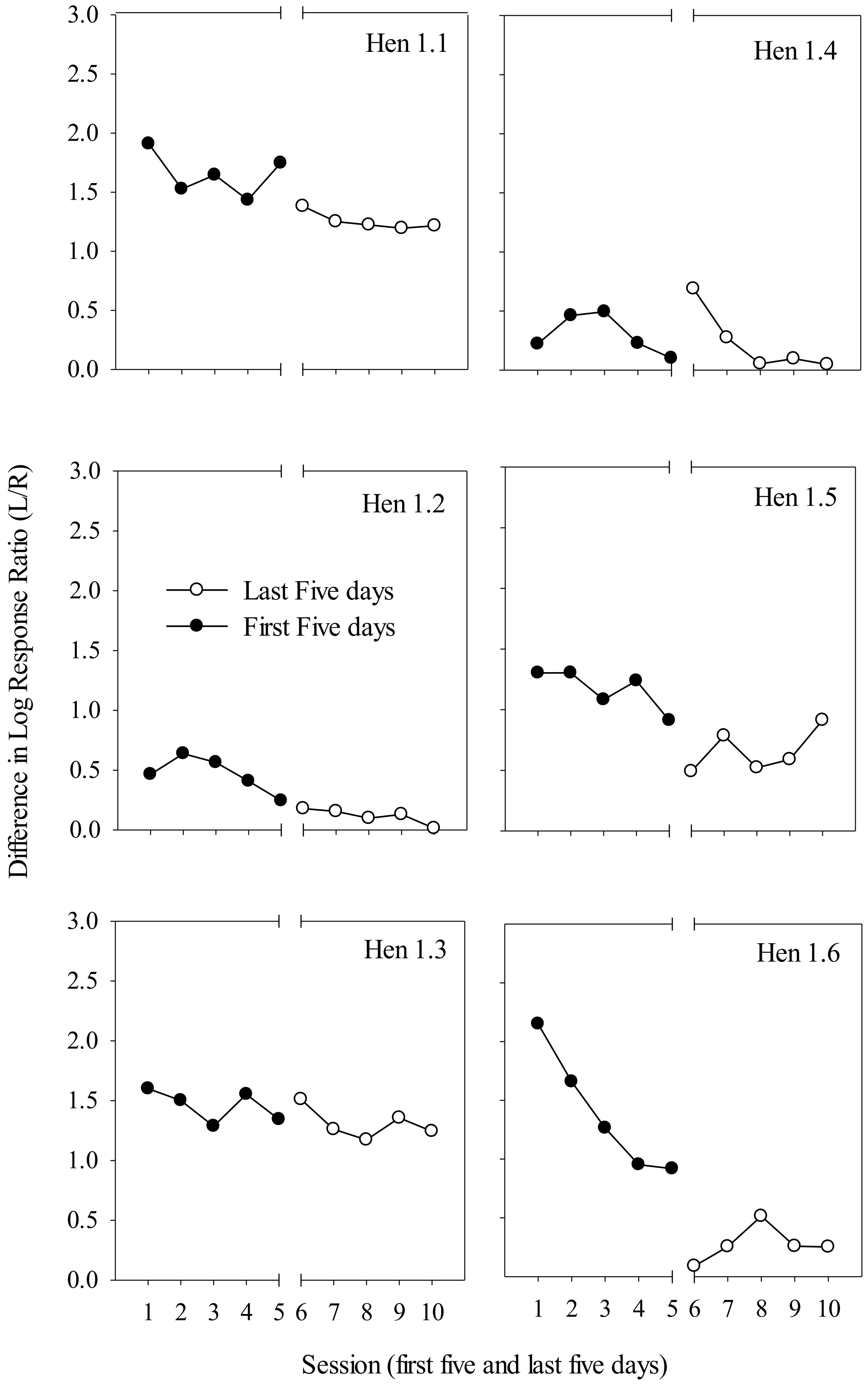

Figure 2: Difference in Log response ratios (Left/Right) between red and green trials for each subject in the first five and last five days in Condition 2.

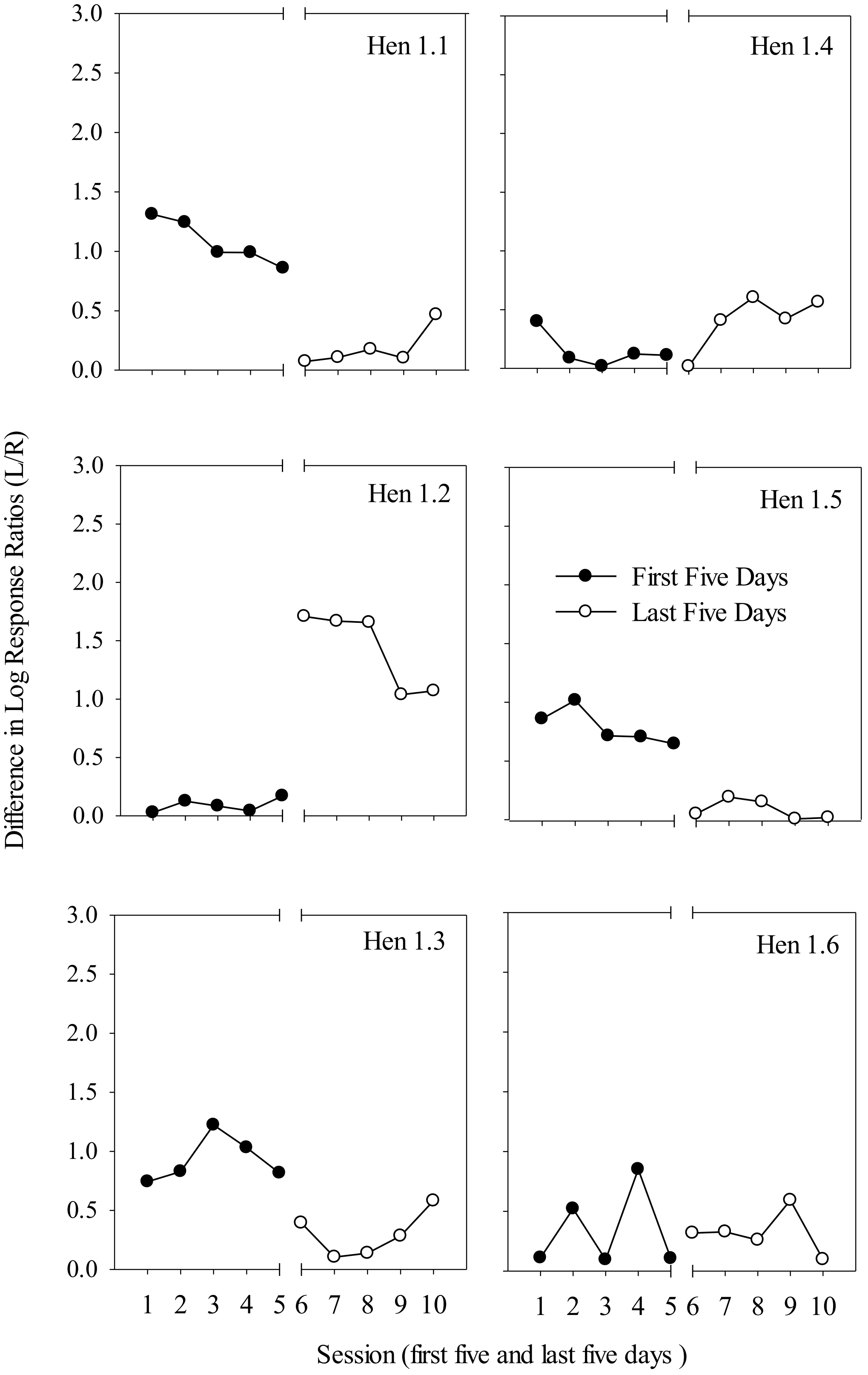

Figure 3: Difference in Log response ratios (Left/Right) between red and green trials for each subject in the first five and last five days of Condition 3.

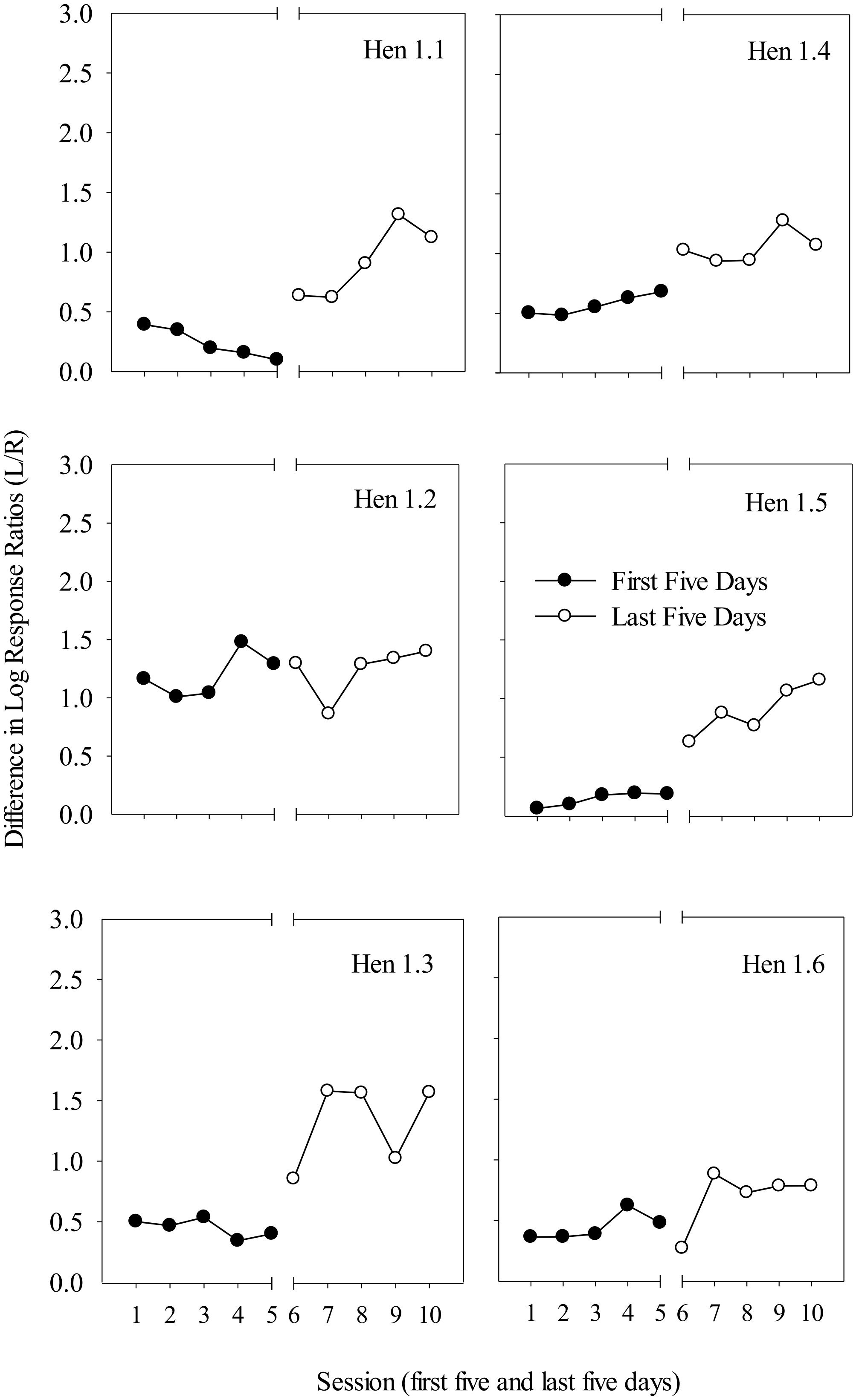

Figure 4: Difference in Log response ratios (Left/Right) between red and green trials for each subject in the first five and last five days of Condition 4.

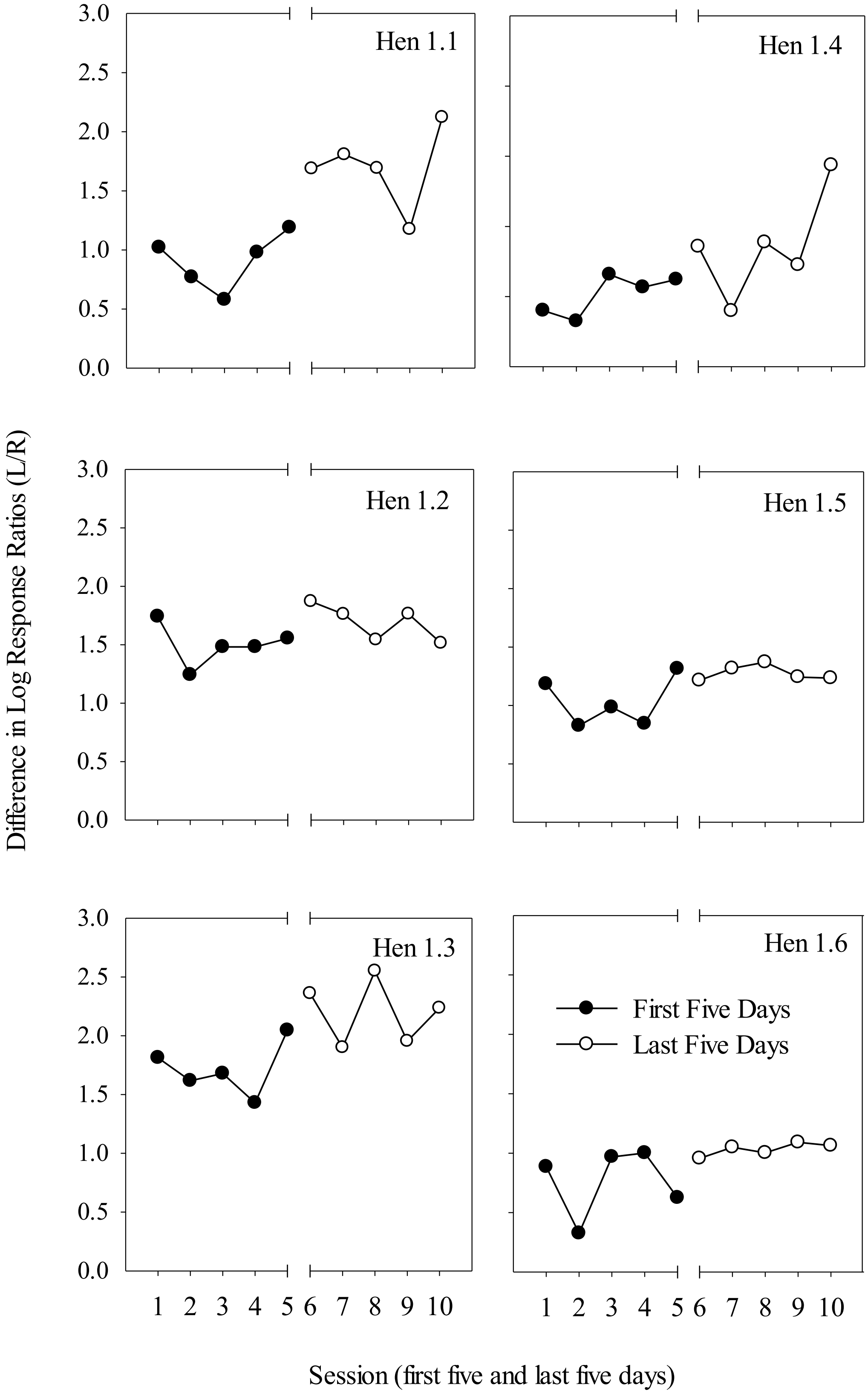

Figure 5: Difference in the response ratios (Left/Right) between red and green trials for each subject in the first five and last five days of Condition 5.

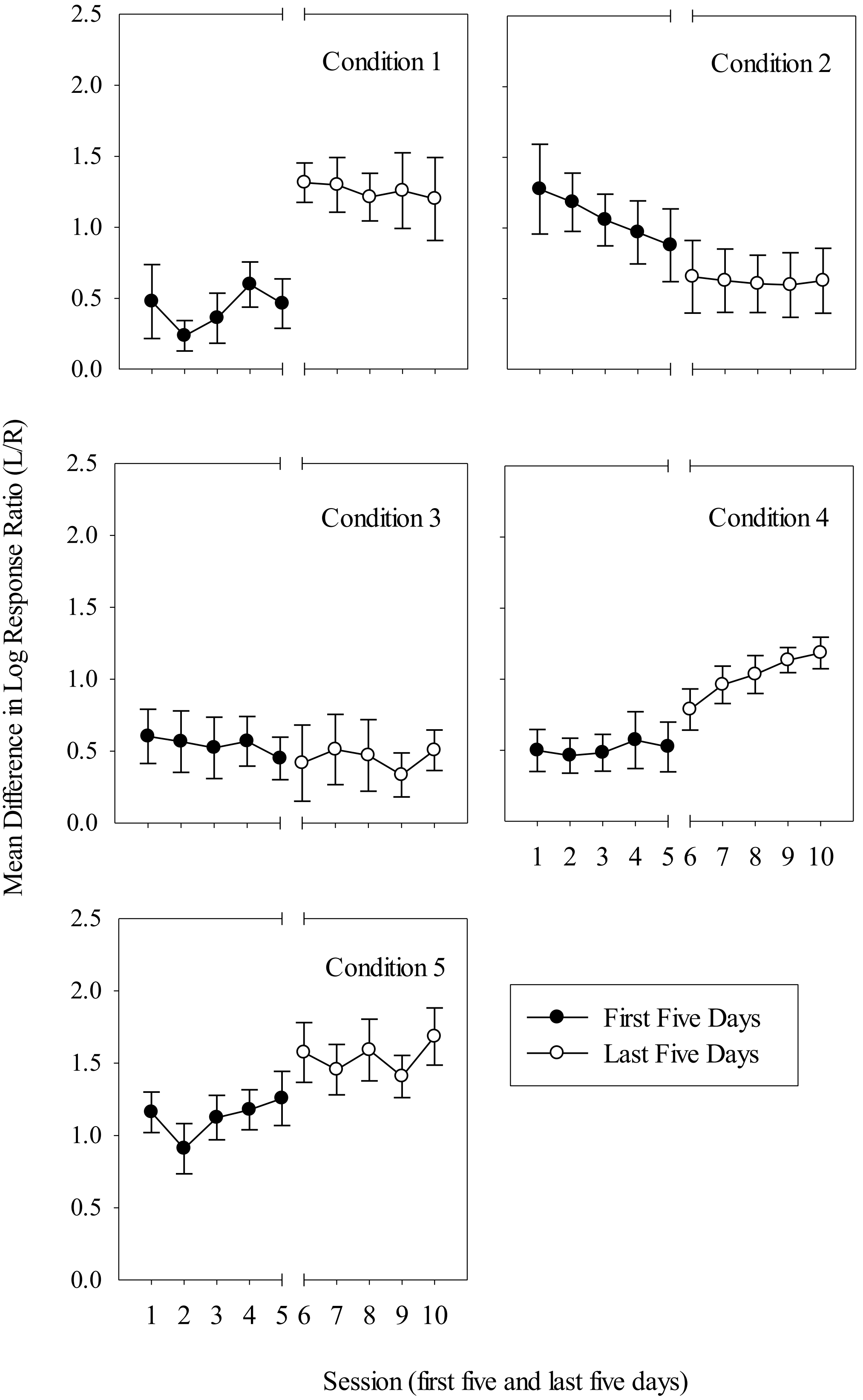

Figure 6: Average difference in Log response ratios (Left/Right) between red and green trials across subjects, for the first five and last five days in each condition. Error bars are one standard error of the mean.

alternatives continued to increase significantly in the last five days of Condition 5 for all six subjects, with Hen 1.1, Hen 1.3 and 1.4 showing the most significant amount of difference in preference between alternatives. Figure 6 shows the average difference in relative preference between red and green alternatives, plotted against the first five and last five days in each Condition. Figure 6 shows an increase in the average difference in Condition 1, with a difference measure of approximately 0.5 in the first five days to an increase of 1.5 in the last five days. The difference between alternatives is then shown to decrease in the first five days in Condition 2 and remains steady at approximately 0.5. Figure 6 shows little difference between alternatives shown in the first five and last five days in Condition 3.

The average difference significantly increases in Condition 4 and Condition 5. Figure 6 shows that Condition 5 has the greatest difference in the average log response ratios between red and green choices. This indicates that Condition 5 had the greatest variation in relative preference between red and green choice trials compared to the other four Conditions.

Log Response Ratios as a measure of relative preference

Figure 7 shows the relative preference for red and green trials for each subject measured as the logarithm of the ratio of responses made to left and right keys, plotted as a function of the log (FI) schedule delay. The filled data points represent red choice trials (4.5-s outcome) and unfilled squares represent green choice trials (1-s outcome). The log response ratios shown in Figure 7, indicate that for all six subjects, the preference for the left, SS alternative (green 1-s outcome) was greater than the right alternative LL outcome (red 4.5-s) when the delay associated with the SS outcome was 2-s in Condition 1.

Figure 7 shows that the preference for the green SS component decreased as the preference for the red LL component increased across successive Conditions as a function of increasing delay. The functions intersected between Condition 2 and 3 for most subjects.

Predictions of the GML and CCM equations.

Figure 7 and Figure 8 show the fits of the CCM and GML equations to the data for each subject, plotted as a function of the log FI schedule delay. In comparison to the GML fits shown in Figure 8, the CCM fits, shown in Figure 7, accounted for a greater percentage of the variance compared to the GML equation (see Table 2 and 3).

Figure 9 shows the fits of the GML and CCM equation applied to the average data (see Table 4). The top panel shows the CCM fit, which accounted for 98% of the variance, compared to the GML equation, shown in the bottom panel which accounted for 89% of the variance. Overall, CCM provided a better description of the average data. Taking into account the effects of overall duration of delay as well as the interaction effects between delay and amount, CCM was able to predict a magnitude effect in the present data as the relative preference of the large reward outcome (Red 4.5-s) increased while preference for the smaller outcome (Green 1-s) decreased as a function of increasing delay.

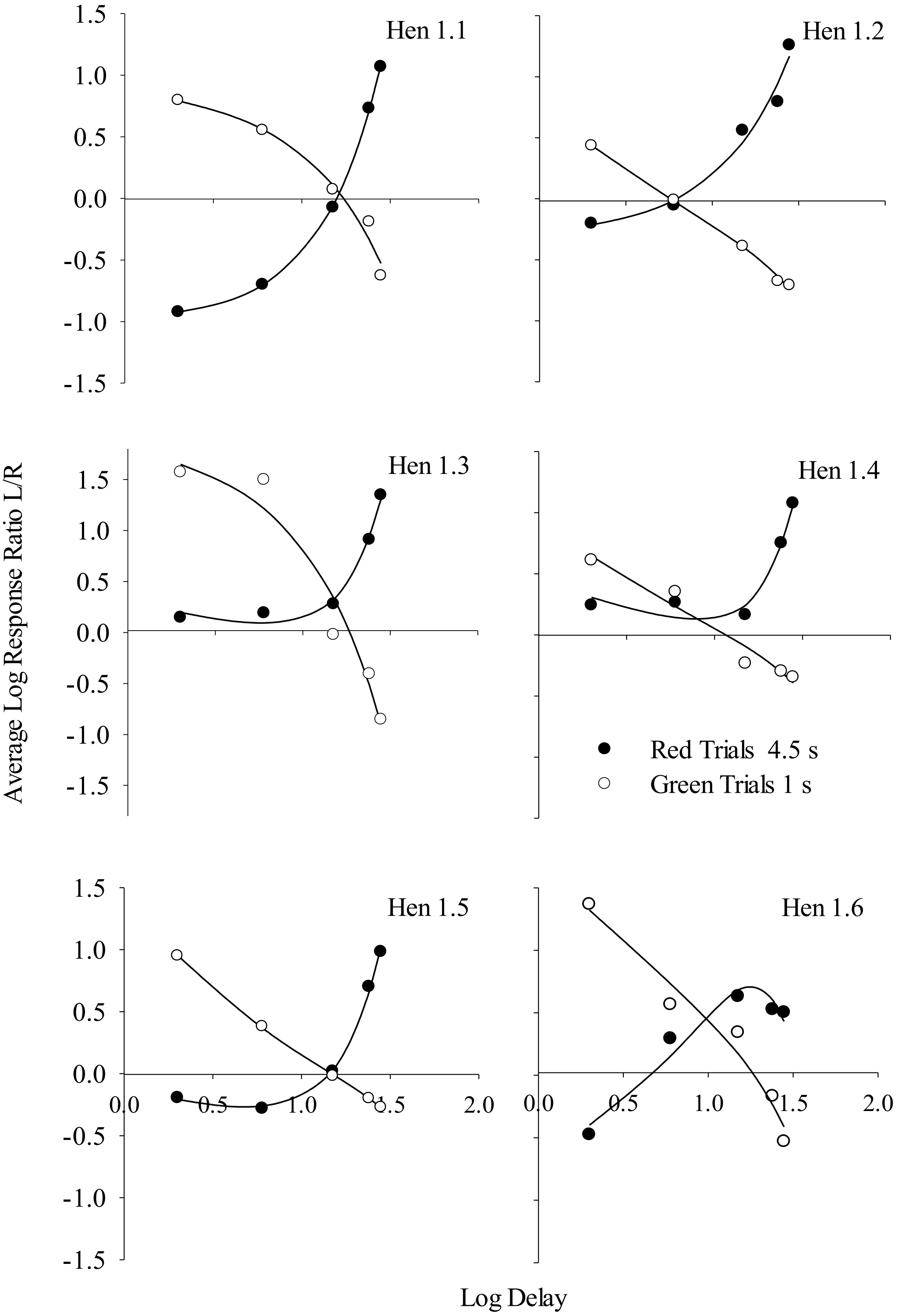

Figure 7: The average response allocation for each subject, measured as the logarithm of the ratio of responses made to left and right alternatives, plotted as a function of the logarithm of the FI schedule values associated with the 4.5-s and 1-s outcome. Each panel shows the fits of the Contextual Choice Model (CCM) (equation 2) for each subject.

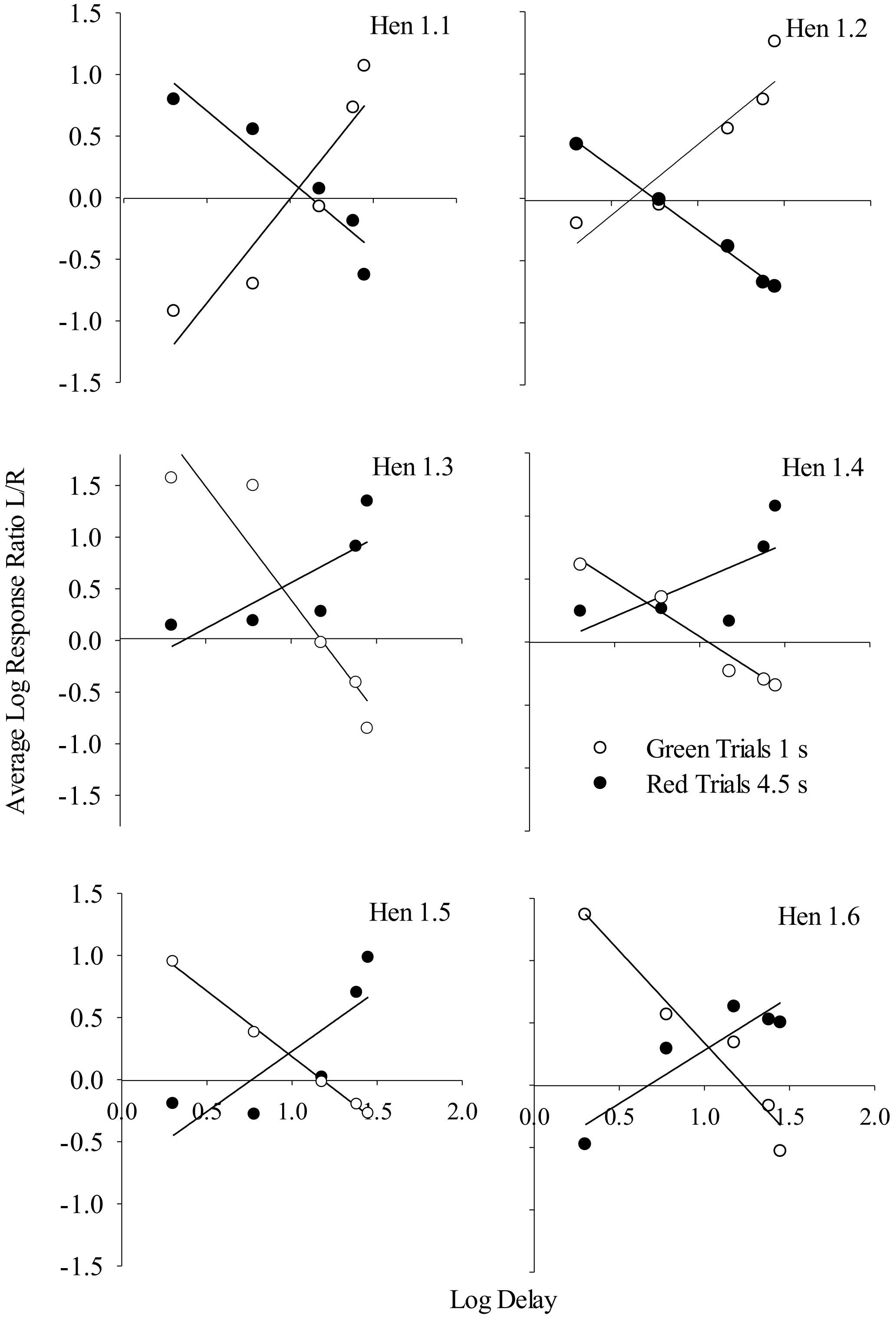

Figure 8: The average response allocation for each subject, measured as the logarithm of the ratio of responses made to left and right alternatives, plotted as a function of the FI schedule values associated with the 4.5-s and 1-s outcomes. Each panel shows the fits of the Generalised Matching Law (GML) (equation1) for each subject across successive conditions.

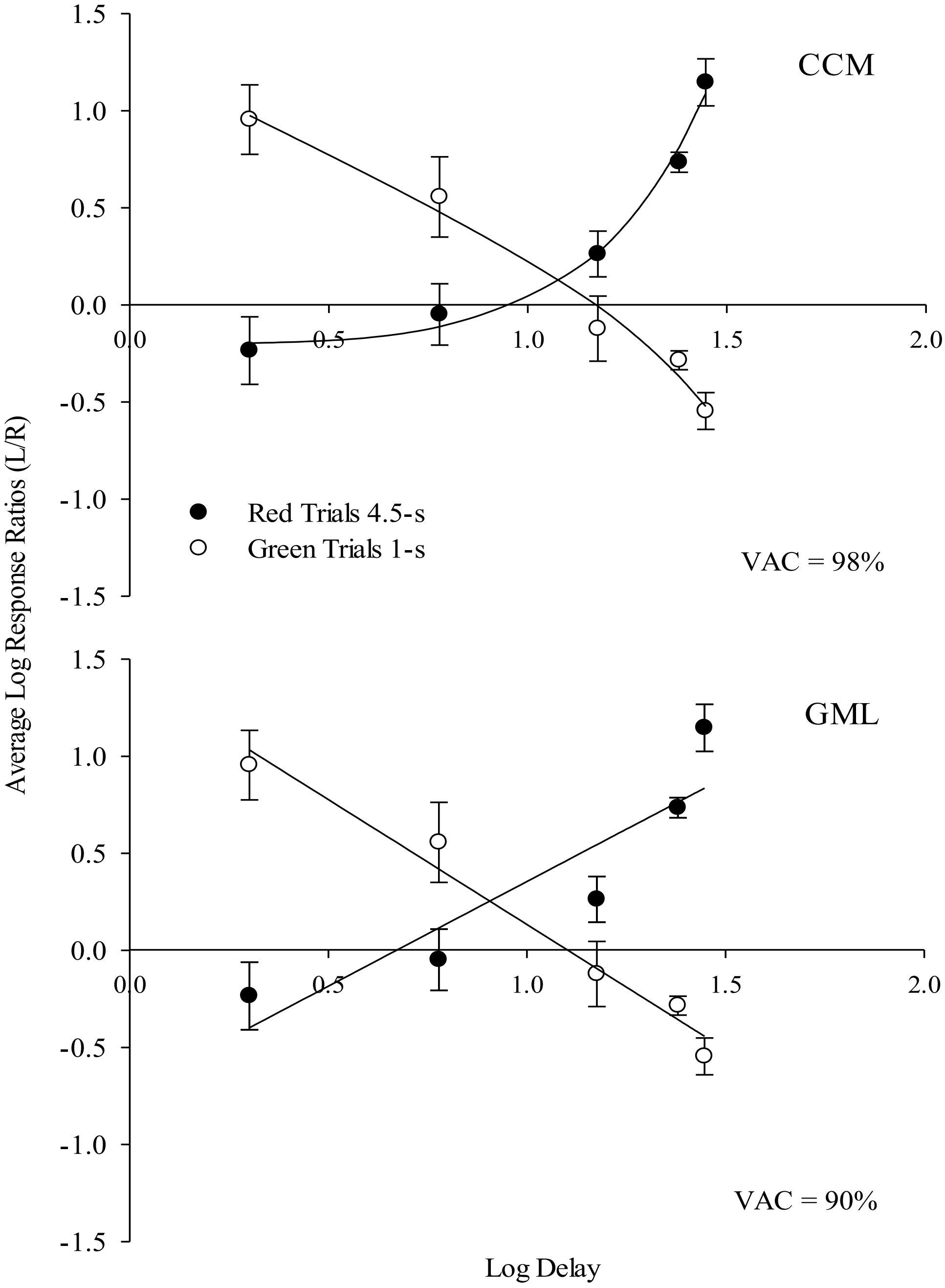

Figure 9: Log response ratios (L/R) averaged across subjects, plotted against the Log of the FI schedule delay associated with the 4.5-s outcome on red trials and 1-s outcome on green trials. Error bars indicate standard error of the mean. The top panel shows the fits of the CCM (equation 2) and the bottom panel shows the fits of the GML (equation 1) to the averaged data.

Table 3. Generalised Matching Law equation (1) parameter values calculated for each subject in red and green choice trials.

Subject	*Hen 1.1*		*Hen 1.2*		*Hen 1.3*	
Parameter	*Red*	*Green*	*Red*	*Green*	*Red*	*Green*
a_D	-1.690	-1.129	-1.136	-1.011	-0.885	-2.193
a_M	-0.170	-2.846	0.382	-2.479	-1.843	-5.459
logb	-1.078	1.493	-0.611	0.914	1.144	2.978
Mean of y	0.021	0.121	0.471	-0.270	0.574	0.357
SE of y	0.456	0.265	0.310	0.045	0.456	0.538
VAC	0.862	0.893	0.869	0.996	0.632	0.883
C I	0.372	0.216	0.253	0.037	0.372	0.440

Subject	*Hen 1.4*		*Hen 1.5*		*Hen 1.6*	
Parameter	*Red*	*Green*	*Red*	*Green*	*Red*	*Green*
a_D	-0.577	-0.896	-0.973	-1.056	-0.854	-1.478
a_M	-1.966	-2.037	-1.458	-2.384	-1.298	-2.415
logb	1.371	0.962	0.501	1.270	0.530	1.256
Mean of y	0.500	0.017	0.245	0.167	0.294	0.315
SE of y	0.404	0.120	0.453	0.039	0.262	0.251
VAC	0.481	0.962	0.678	0.997	0.829	0.941
CI	0.330	0.098	0.370	0.032	0.214	0.205

Table 4. Contextual Choice Model equation (2) parameter values calculated for each subject in red and green choice trials.

Subject	*Hen 1.1*		*Hen 1.2*		*Hen 1.3*	
Parameter	*Red*	*Green*	*Red*	*Green*	*Red*	*Green*
a_D	-1.830	-0.134	-0.197	-1.303	-5.580	-0.199
a_M	-0.166	-2.061	2.043	0.559	-9.333	-4.092
logb	-0.908	1.986	-0.392	-1.422	1.010	4.093
Mean of y	0.021	0.121	0.471	-0.270	0.574	0.357
SE of y	0.019	0.126	0.148	0.036	0.090	0.339
VAC	1.000	0.976	0.970	0.997	0.986	0.954
C I	0.016	0.103	0.121	0.029	0.074	0.277
Subject	*Hen 1.4*		*Hen 1.5*		*Hen 1.6*	
Parameter	*Red*	*Green*	*Red*	*Green*	*Red*	*Green*
a_D	-5.708	-1.192	-4.894	-1.867	8.633	-1.522
a_M	-10.226	0.583	-7.749	1.607	18.944	0.019
logb	1.198	-1.103	0.467	-2.237	-2.049	-0.436
Mean of y	0.500	0.017	0.245	0.167	0.294	0.315
SE of y	0.113	0.135	0.042	0.013	0.140	0.196
VAC	0.960	0.952	0.997	1.000	0.951	0.964
CI	0.092	0.111	0.034	0.011	0.114	0.160

Table 5. Contextual Choice Model and Generalised Matching Law equation parameter values for average data.

Equation Parameter	*GML*		*CCM*	
	Red	*Green*	*Red*	*Green*
a_D	-1.077	-1.288	-2.305	-1.260
a_M	-0.630	-0.094	-2.397	-0.094
logb	0.013	-0.382	0.013	-0.407
Mean of y	0.372	0.112	0.372	0.112
SE of y	0.339	0.144	0.086	0.117
VAC	0.821	0.973	0.989	0.982
CI	0.277	0.118	0.070	0.096

Discussion

The aim of the present study was to determine if a magnitude effect could be obtained with hens responding on a multiple concurrent-chains procedure, in a classic self-control situation. In concurrent-chains procedures, such as the one used in the present experiment, a magnitude effect would be evident if the ratio of responding in the choice phase was greater on the alternative related to the LL reward, compared to the ratio of responding to the alternative related to the SS reward in the outcome phase (Kinloch & White, 2013; Ong & White, 2013).

The results indicate that a magnitude effect was obtained. The subjects' measure of preference varied with systematic changes in amount and delay to reward. The hens showed a greater relative preference for the LL reward compared to the SS reward over increasing delay. As hypothesised, the present study was able to replicate and extend the findings of Grace et al., (2012) to another species. The results also provide further evidence that a magnitude effect can be demonstrated with non-human animals.

The present findings and the results of Grace et al., (2012) are inconsistent with previous research. The reasons behind why the present experiment succeeded in obtaining a magnitude effect, while many previous studies did not, is likely to be related to issues of procedural design, specifically with contrast effects and a lack of discriminability between small and large rewards (Grace et al., 2012; Ong & White, 2004).

An example of this can be seen in adjusting amount procedures, in which *indifference points* are measured to determine relative preference between standard and adjusting alternatives. The standard amounts in such procedures do not vary within each session but only change between successive conditions (Richards et al., 1997). In contrast, the concurrent-chain procedure used in the present study was designed so that the LL ‘standard’ amount changed between red and green trials within each session. It may be that choice was more sensitive to the difference in the size of the rewards due to repeatedly experiencing both SS and LL outcomes. The magnitude effect in the current study was most likely to have been maintained by an increased ability to discriminate between the alternatives on a trial-by-trial basis within each session (Grace et al., 2012).

Evidence of this was also discussed by Landon et al., (2003) in their study that looked at reinforcer magnitude effects on concurrent-chains. Although they did not find a significant magnitude effect, the researchers did observe a linear relation between log response ratios and log magnitude ratios, that had been absent from many previous studies. Landon et al., (2003) suggested that this may have been due to the LL and SS outcome being presented at the same time while the over-all reinforcer magnitude was held constant across trials; this differed from previous studies that held one alternative constant and varied the other alternative across presentations (Landon et al., 2003 & Davison & Hogsden, 1984).

It has been suggested that the absence of a magnitude effect in adjusting amount procedures may also be due to the time delay between response opportunities on each trial. A study by Mazur and Biondi (2011) found that as the time between trials increased, the subjects’ indifference points also increased. Grace et al., (2012) proposed that a magnitude effect could be obtained in adjusting amount procedures if the ITI were made shorter so that choice could be more sensitive to the size of the reward (Grace et al., 2012; Mazur & Biondi, 2011).

The few studies that used concurrent-chain procedures to test for a magnitude effect also failed to find evidence with non-human animals (Grace, 1999; Ong & White, 2004). The results of the present study support the use of non-independent scheduling in choice trials to ensure that the outcome phase is entered an equal number of times on left and right keys (Ong & White, 2004; Grace et al., 2012). Although concurrent-chain procedures are not commonly used in temporal discounting research with non-humans, the present experiment and other recent studies have shown that concurrent chains can provide a viable alternative method for investigating the effects that interaction between delay and amount have on relative value (Grace et al., 2012; Kinloch & White 2013).

The magnitude effect obtained in the present study was based a measure of preference indicated by the relative response rate on each alternative. It has been noted that this method of researching magnitude effects with non-humans is considerably different from the way that magnitude effects are established in human participants, whose choices have been found to be affected by variables such as level of income and other lifestyle factors (Oliveira, Calvert, Green & Myerson, 2012).

Nevertheless, research on the magnitude effect in temporal discounting with concurrent chains has been further expanded on by Kinloch and White (2013) who replicated the same procedure by Grace et al., (2012) with human participants, who were instructed to make choices between hypothetical monetary rewards. Kinloch and White (2013) were able to demonstrate a magnitude effect in the data of their study. This provided evidence that the procedure used in the current study is also effective in establishing a magnitude effect with human participants and so increased cross-species generality of the results (Kinloch & White, 2013).

Discussion of The General Matching Law and Contextual Choice Model

Application of the GML and CCM to the average log response ratios over the log delay for each subject determined that, although both equations provided adequate fits, the CCM accounted for a higher percentage of variance compared to the GML. The highly accurate representation of the data by the CCM is likely due to the additional exponents, which take into account context effects of choice in the procedure (Grace & Hucks, 2013). The result of the added exponent has meant that the CCM will usually have a higher percentage of variance accounted for compared to the GML (Grace, 1994; Grace, 1996).

It is important to note that the GML and CCM equations equate to the same framework of choice and albeit for the additional exponent, they are arguably both achieving the same function, however the CCM is non-linear and so is better able to describe certain data sets. Therefore, the question of which model provides a better description in terms of variance accounted for should be apparent from the parameters of each equation (Grace, 1996; Grace & Hucks, 2013).

The CCM has been proved to be a valid method of describing behavioural choice in concurrent chains; however it is limited because the model calculates terminal link values as a function of the average delay to reward and so cannot account for preference for variability in reinforcer distribution (Grace & Hucks, 2013). Despite this, the CCM has contributed to the development of the matching law by extending the GML equation to incorporate data from concurrent chains in order to allow the effects of variables such as reinforcer magnitude to be effectively analysed (Grace, 1994; Grace & Hucks, 2013).

Conclusion

The magnitude effect is advantageous because it increases the likelihood that an organism will gain access to larger, although delayed rewards that maximise the long term benefit to the animal (Beeby & White, 2013; Kinloch & White, 2013). From an evolutionary perspective, the choice to wait for a larger over a smaller, immediate reward is also adaptive and therefore would be an expected trait in both humans and non-human animals (Grace et al., 2012; Kinloch & White, 2013).

The results of the present study and other recent experiments may be useful in clarifying suggestions that the magnitude effect is unique to humans, as well as the view that humans and animals discount the amount of rewards in different ways (Calvert et al., 2010; Grace et al., 2012; Green & Myerson, 2004). The current study may have benefited from further extension of the procedure by varying the durations of reinforcement to test whether the magnitude effect could be eliminated after it was obtained. This could have provided more information on the effect that the interaction of the different amounts and delay exerted on relative response rates in the current procedure.

The present findings create possibilities for further research with non-humans, which may be practical in building on the current understanding of the role of reward magnitude in the way that humans and animals make decisions in various self-control situations. Research on the mechanisms that underlie choice behaviour has many relevant applications for both research and treatment, ranging from being better able to predict consumer behaviour, to treating various problems such as drug or gambling addiction.

References

Ainslie, G., & Herrnstein, R., J. (1981). Preference reversal and delayed reinforcement. *Animal Learning and Behavior*, *9*(4), 476–482. doi:10.3758/BF03209777

Baum, W. M., & Rachlin, H. (1969) Choice as time allocation. *Journal of the Experimental Analysis of Behavior, 12*(6), 485-489. doi: 10.1901/jeab.1969.12-861

Beeby, E., & White, K. G. (2013). Preference reversal between impulsive and self-control choice. *Journal of the Experimental Analysis of Behavior*, *99*(3), 260–276. doi:10.1002/jeab.23

Bonem, M., & Crossman, E. K. (1988). Elucidating the effects of reinforcement magnitude. *Psychological Bulletin*, *104*(3), 348–362. doi: 10.1037/0033-2909.104.3.348

Calvert, A. L., Green, L., & Myerson, J. (2010). Delay discounting of qualitatively different reinforcers in rats. *Journal of the Experimental Analysis of Behavior*, *93*(2), 171–84. doi:10.1901/jeab.2010.93-171

Chapman, G. B. (1996). Temporal discounting and utility for health and money. *Journal of Experimental Psycholog. Learning, Memory, and Cognition*, *22*(3), 771-791. pp. 771–791). doi:10.1037/0278-7393.22.3.771

Davison, M., & Baum, W. M. (2003). Every reinforcer counts: Reinforcer magnitude and local preference. *Journal of the Experimental Analysis of Behavior*, *80*(1), 95–129. doi:10.1901/jeab.2003.80-95

Davison, M., & Hogsden, I. (1984). Concurrent variable-interval schedule performance: Fixed versus mixed reinforcer durations. *Journal of the Experimental Analysis of Behaviour, 41*(2), 169-182. doi:10/1901/jeab.1984.41-169

Freeman, K., Green, L., Myerson, J. & Woolverton, W. (2009). Delay discounting of saccharin in rhesus monkeys. *Behavioural processes, 82*(2), 214-218. doi: 10.1016/j.beproc.2009.06.002

Grace, R. C. (1994). A contextual choice model of concurrent-chains choice. *Journal of the Experimental Analysis of Behavior*, *61*(1), 113–129. doi: 10.1901/jeab.1994.61-113

Grace, R. C. (1996). Choice between fixed and variable delays to reinforcement in the adjusting-delay procedure and concurrent chains. *Journal of Experimental Psychology: Animal Behavior Processes*, *22*(3), 362–383. doi:10.1037//0097-7403.22.3.362

Grace, R. C. (1999). The matching law and amount-dependent exponential discounting as a accounts of self-control choice. *Journal of the Experimental Analysis of Behavior*, *1*(71), 27–44. doi: 10.1901/jeab.1999.71-72

Grace, R. C., & Hucks, A. D. (2013). The allocation of operant behaviour. In G. J. Madden, W. V. Dube, T. D. Hackenburg, G. P. Hanley & K. A. Lattal (Eds.), *APA handbook of behaviour analysis, Vol. 1: Methods and principles* (pp.307-337). Washington, D.C, US: American Psychological Association

Grace, R. C., & McLean, A. P. (2005). Integrated versus segregated accounting and the magnitude effect in temporal discounting. *Psychonomic Bulletin & Review*, *12*(4), 732–739. doi: 10.3758/BF03196765

Grace, R. C., Sargisson, R. J., & White, K. G. (2012). Evidence for a magnitude effect in temporal discounting with pigeons. *Journal of Experimental Psychology. Animal Behavior Processes*, *38*(1), 102–8. doi:10.1037/a0026345

Green, L., & Estle, S. J. (2003). Preference reversals with food and water reinforcers in rats. *Journal of the Experimental Analysis of Behavior*, *79*(2), 233–242. doi:10.1901/jeab.2003.79-233

Green, L., Fisher, E. B., Perlow, S., & Sherman, L. (1981). Preference reversal and self control: Choice as a function of reward amount and delay. *Behaviour Analysis Letters*, *1*(1), 43–51. doi: 19820-00496-001

Green, L., & Myerson, J. (2004). A discounting framework for choice with delayed and probabilistic rewards. *Psychological Bulletin*, *130*(5), 769–792. doi:10.1037/0033-2909.130.5.769

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*(1), 39–50. doi:10.1901/jeab.2004.81-39

Green, L., Myerson, J., & McFadden, E. (1997). Rate of temporal discounting decreases with amount of reward. *Memory & Cognition*, *25*(5), 715–723. doi:10.3758/BF03211314

Holt, D. D., Green, L., & Myerson, J. (2012). Estimating the subjective value of future rewards: Comparison of adjusting-amount and adjusting-delay procedures. *Behavioural Processes*, *90*(3), 302–310. doi:10.1016/j.beproc.2012.03.003

Johnson, M. W., & Bickel, W. K. (2002). Within-subject comparison of real and hypothetical money rewards in delay discounting. *Journal of the Experimental Analysis of Behavior*, *77*(2), 129–146. doi:10.1901/jeab.2002.77-129

Kinloch, J. M., & White, K. G. (2013). A concurrent-choice analysis of amount-dependent temporal discounting. *Behavioural Processes*, *97*,(1), 1–5. doi:10.1016/j.beproc.2013.03.007

Kirby, K. N. (1997). Bidding on the future: Evidence against normative discounting of delayed rewards. *Journal of Experimental Psychology: General*, *126*(1), 54–70. doi:10.1037//0096-3445.126.1.54

Landon, J., Davison, M., & Elliffe, D. (2003). Concurrent schedules: Reinforcer magnitude effects. *Journal of the Experimental Analysis of Behavior*, *79*(3), 351–365. doi:10.1901/jeab.2003.79-351

Mazur, J. E. (1984). Tests of an equivalence rule for fixed and variable reinforcer delays. *Journal of Experimental Psychology: Animal Behavior Processes*, *10*(4), 426–436. doi:10.1037//0097-7403.10.4.426

Mazur, J. E. (2000). Two-versus three-alternative concurrent-chain schedules: A test of three models. *Journal of Experimental Psychology. Animal Behavior Processes*, *26*(3), 286–293. doi. 10.1037/0097-7403.26.3.286

Mazur, J. E., & Biondi, D. R. (2011). Effects of time between trials on rats' and pigeons' choices with probabilistic delayed reinforcers. *Journal of the Experimental Analysis of Behavior*, *95*(1), 41–56. doi:10.1901/jeab.2011.95-41

Myerson, J., & Green, L. (1995). Discounting of delayed rewards: Models of individual Choice. *Journal of the Experimental Analysis of Behavior*, 3(3), 263–276. doi: 10.1901/jeab.1995.64-263

Oliveira, L., Calvert, A. L., Green, L. & Myerson, J. (2012). Level of deprivation does not affect degree of discounting in pigeons. *Learning and Behavior,41*(2), 148-158. doi: 10.3758/s14320-012-0092-4

Ong, E. L., & White, K. G. (2004). Amount-dependent temporal discounting? *Behavioural Processes*, *6*(3), 201–212. doi:10.1016/j.beproc.2004.03.005

Rachlin, H., & Green, L. (1972). Commitment, choice and self-control. *Journal of the Experimental Analysis of Behavior*, *17*(1), 15–22. doi:10.1901/jeab.1972.17-15

Rapoport, A., Benzion, U., & Yagil, J. (1989). Discount rates inferred from decisions: An experimental study. *Management Science*, *35*(3), 270-284. doi:10.1287/mnsc.35.3.270

Richards, J. B., Mitchell, S. H., de Wit, H., & Seiden, L. S. (1997). Determination of discount functions in rats with an adjusting-amount procedure. *Journal of the Experimental Analysis of Behavior*, *67*(3), 353–366. doi:10.1901/jeab.1997.67-353

Rodriguez, M. L., & Logue, A. W. (1988). Adjusting delay to reinforcement: Comparing choice in pigeons and humans. *Journal of Experimental Psychology. Animal Behavior Processes*, *14*(1), 105–117. doi: 10.1037/0097-7403.14.1.105

Tayler, S., Arantes, J., & Grace, R. C. (2009). Temporal discounting for monetary and close relationship outcomes. *Personal Relationships*, *16*(3), 385–400. doi:10.1111/j.1475-6811.2009.01229.x

Thaler, R. (1981). Some empirical evidence on dynamic inconsistency. *Economics Letters*, *8*(3), 201–207. doi:10.1016/0165-1765(81)90067-7

Appendix A

Table A1: Average Log response ratios (L/R) for each subject in each condition in red and green trials.

Hen 1.1	*Red Trials (L/R)*	*Green Trials (L/R)*
Condition 1	-0.9227	0.7962
Condition 2	-0.7005	0.5531
Condition 3	-0.0733	0.0711
Condition 4	0.7305	-0.1900
Condition 5	1.0686	-0.6278
Hen 1.2		
Condition 1	-0.2025	0.4344
Condition 2	-0.0543	-0.0107
Condition 3	0.5588	-0.8699
Condition 4	0.7933	-0.4441
Condition 5	1.2582	-0.70917
Hen 1.3		
Condition 1	0.1444	1.5712
Condition 2	0.1887	1.4972
Condition 3	0.2780	-0.0220
Condition 4	0.9100	-0.4074
Condition 5	1.3464	-0.8532
Hen 1.4		
Condition 1	0.2433	0.6118
Condition 2	0.2644	0.3519
Condition 3	0.1636	-0.2327
Condition 4	0.7516	-0.2992
Condition 5	1.0768	-0.2839
Hen 1.5		
Condition 1	-0.1946	0.9495
Condition 2	-0.2809	0.3799
Condition 3	0.0180	-0.0198
Condition 4	0.7003	-0.1999
Condition 5	0.9824	-0.2724
Hen 1.6		
Condition 1	-0.4770	1.3665
Condition 2	0.2911	0.5651
Condition 3	0.6291	0.3410
Condition 4	0.5245	-0.1681
Condition 5	0.5013	-0.5308

Table A2: Average Log response ratio, standard deviation and standard error of the mean, across subjects for each condition.

Averaged Across Subjects	*Average Log Response ratio*	*Standard Deviation*	*Standard Error*
Condition 1			
Red	-0.2349	0.4259	0.1738
Green	0.9550	0.4388	0.1791
Condition 2			
Red	-0.0486	0.3869	0.1580
Green	0.5561	0.5060	0.2065
Condition 3			
Red	0.2623	0.2845	0.1161
Green	-0.1220	0.41080	0.1677
Condition 4			
Red	0.7350	0.1263	0.0515
Green	-0.2848	0.1186	0.0484
Condition 5			
Red	1.0389	0.2956	0.1207
Green	-0.5462	0.2329	0.0951

Table A3: Outcome (FI) schedule delay (s) and Log delay across conditions

Condition	*Delay (s)*	*Log Delay*
Condition 1	2 s	0.3010
Condition 2	6 s	0.7782
Condition 3	15 s	1.1761
Condition 4	24 s	1.3802
Condition 5	28 s	1.4471

Table A4: Difference between Log response ratios for each subject in the first and last five days of Condition 1.

First Five Days	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*
1	0.1726	0.0426	1.6351	0.0864	0.1099	0.8233
2	0.1966	0.1893	0.0133	0.2003	0.0747	0.7469
3	0.4003	0.1227	0.0247	0.3850	0.0559	1.1755
4	0.1997	0.3622	1.2288	0.8375	0.3022	0.6553
5	0.2860	0.0969	1.1568	0.7959	0.0847	0.3591

Last Five Days	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*
1	1.7066	1.0878	1.4297	0.9124	1.0661	1.6831
2	1.7829	0.6999	1.3326	0.9925	1.0734	1.9117
3	1.1945	0.7565	1.3557	0.9234	1.1124	1.9342
4	2.0121	0.4458	1.5198	0.5411	1.2098	1.8204
5	1.8990	0.1950	1.4957	0.4821	1.2592	1.8685

Table A5: Difference between Log response ratios for each subject in the first and last five days of Condition 2

First Five Days	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*
1	1.910	0.4646	1.5993	0.2229	1.3026	2.1498
2	1.5269	0.6390	1.501	0.4624	1.3047	1.6582
3	1.6463	0.5656	1.2870	0.4945	1.0826	1.2641
4	1.4343	0.4085	1.5529	0.2282	1.2382	0.9526
5	1.7476	0.2428	1.3429	0.1014	0.9123	0.9181

Last Five Days	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*
1	1.3825	0.1782	1.5105	0.2746	0.4915	0.0899
2	1.2509	0.1550	1.2601	0.0539	0.7859	0.2549
3	1.2227	0.0976	1.1733	0.0969	0.5217	0.5143
4	1.1956	0.1297	1.3555	0.0479	0.5908	0.2589
5	1.2162	0.0133	1.2429	0.1227	0.9147	0.2520

Table A6: Difference between Log response ratios for each subject in the first and last five days of Condition 3

First Five Days	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*
1	1.3116	0.0273	0.7431	0.3996	0.8604	0.2773
2	1.2430	0.1255	0.8277	0.0884	1.0170	0.0995
3	0.9913	0.0827	1.2229	0.0193	0.7144	0.1110
4	0.9903	0.0408	1.0314	0.1233	0.7064	0.5219
5	0.8579	0.1700	0.8153	0.1119	0.6469	0.0947

Last Five Days	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*
1	0.0735	1.7083	0.3941	0.0177	0.0488	0.2600
2	0.1073	1.6682	0.1040	0.4078	0.1920	0.5924
3	0.1755	1.6575	0.1377	0.6044	0.1520	0.0978
4	0.1027	1.0392	0.2831	0.4225	0.0067	0.1536
5	0.4686	1.0703	0.5817	0.5647	0.0170	0.3366

Table A7: Difference between Log response ratios for each subject in the first and last five days of Condition 4

First Five Days	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*
1	0.3942	1.1627	0.5011	0.5026	0.0636	0.3660
2	0.3485	1.009	0.4674	0.4828	0.0988	0.3677
3	0.1962	1.0403	0.5369	0.5510	0.1783	0.3893
4	0.1580	1.4788	0.3438	0.6287	0.1928	0.6258
5	0.0999	1.2904	0.3998	0.6799	0.1881	0.4821

Last Five Days	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*
1	0.6376	1.2958	0.8540	1.0290	0.6307	0.2743
2	0.6227	0.8632	1.5792	0.9364	0.8773	0.8839
3	0.9042	1.2874	1.5627	0.9434	0.7691	0.7304
4	1.3143	1.3406	1.0226	1.2748	1.0659	0.7866
5	1.1239	1.4004	1.5688	1.0705	1.1583	0.7873

Table A8: Difference between Log response ratios for each subject in the first and last five days of Condition 5

First Five Days	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*
1	1.0203	1.1613	1.8127	0.9004	1.1843	0.8846
2	0.7693	1.0874	1.6175	0.8249	0.8275	0.3250
3	0.5791	1.3771	1.6780	1.1568	0.9842	0.9675
4	0.9799	1.7426	1.4293	1.0667	0.8444	1.0013
5	1.1889	1.2436	2.0457	1.1222	1.3142	0.6232

First Five Days	*1.1*	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*
1	1.6878	1.8720	2.3593	1.3568	1.2153	0.9548
2	1.8070	1.7615	1.8991	0.8979	1.3172	1.0495
3	1.6912	1.5429	2.5509	1.3873	1.3708	1.0022
4	1.1749	1.7627	1.9532	1.2250	1.2426	1.0909
5	2.1215	1.5151	2.2355	1.9366	1.2341	1.0631

Table A9: Average difference between Log response ratios (L/R) and standard error of the mean for the first and last five days of each condition

Condition 1	*Average First Five Days*	*Standard Error*	*Average Last Five Days*	*Standard Error*
Day 1	0.47835	0.26011	1.314	0.5365
Day 2	0.2368	0.1067	1.2988	0.5302
Day 3	0.3607	0.1759	1.2127	0.4951
Day 4	0.5976	0.1591	1.2581	0.5136
Day 5	0.4632	0.1743	1.1999	0.4898
Condition 2				
Day 1	1.2749	0.3182	0.6545	0.2568
Day 2	1.1820	0.2062	0.6268	0.2239
Day 3	1.0567	0.1827	0.6044	0.2029
Day 4	0.9691	0.2231	0.5964	0.2286
Day 5	0.8775	0.2569	0.6269	0.2295
Condition 3				
Day 1	0.6032	0.1885	0.4171	0.2649
Day 2	0.5668	0.2136	0.5120	0.2440
Day 3	0.5236	0.2131	0.4708	0.24933
Day 4	0.5690	0.1722	0.3346	0.1528
Day 5	0.4495	0.1480	0.5065	0.1410
Condition 4				
Day 1	0.4984	0.1481	0.7869	0.1450
Day 2	0.4624	0.1229	0.9605	0.1316
Day 3	0.482	0.1293	1.0329	0.1330
Day 4	0.5714	0.1996	1.1342	0.0880
Day 5	0.5234	0.1752	1.1849	0.1109
Condition 5				
Day 1	1.1606	0.1401	1.5744	0.2064
Day 2	0.9086	0.1739	1.4554	0.1740
Day 3	1.1238	0.1541	1.5909	0.2137
Day 4	1.1774	0.1385	1.4083	0.1459
Day 5	1.2563	0.1870	1.6843	0.1980

Appendix B

Excel files with complete summary data for each subject are attached on the accompanying CD.

Appendix C

Ethics approval (protocol number: 888), and completed animal statistics form is attached on the accompanying CD.

Appendix D

Software program (Med-IV) in text format is attached on the accompanying CD.

Appendix E

The body weights of each hen and post feeds during experimentation are attached on the accompanying CD.