Master thesis

Learning in Complex Systems-Behavioral Analysis

2013

Article I: A review of important findings from delay discounting research

Article II: Effects of increasing, decreasing, and constant delays of reinforcement on choice behavior in rats

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Abstract

The subject of delay discounting has been widely studied within the frames of behavioral science. Human and non-humans have been shown to increasingly prefer a smaller sooner reward over a larger later one, when the delay preceding the last is increased. A hyperbolic function has proven effective in describing delay discounting in both humans and non-humans. Further, a number of factors have been found to affect rates of discounting. For example, children tend to discount delayed rewards at a higher rate than adults and small rewards are discounted more steeply than large rewards. Delay discounting has also been investigated as a measure of impulsivity: choosing a smaller sooner reward over a larger later reward can be referred to as impulsive choice behavior. Another area that has received considerable attention is the connection between addiction and higher discounting rates of delayed outcomes. People suffering from various addictions have been found to show a greater preference for immediate rewards over larger delayed rewards that control participants without reported addictions. Article I reviews some of the published literature on delay discounting and discusses important findings in delay discounting research. Article II consists of an empirical study that investigates the effects of gradually increasing or decreasing the delay preceding a larger reward as well as keeping the delay constant. This study was conducted with four Wistar rats. Results show that the percentage of responses leading to the larger delayed reward decreased as the delay preceding the delivery of this reward increased. However, this response percentage did not increase as the delay decreased, nor stabilize as the delay was kept constant. These results indicate that responding might have been affected by other variables (such as previous conditions) than the current contingencies.

Key words: Delay discounting, increasing delay, decreasing delay, constant delay, larger later reward, smaller sooner reward, impulsivity

A review of important findings from delay discounting research

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Abstract

Delay discounting refers to a decrease in the subjective value of a reward as a function of the duration of time until its receipt. Article I provides a review of some important findings from published literature on the subject of delay discounting. Firstly, both humans and non-humans discount larger rewards as the delay to their receipt increase. Extensive evidence suggests that discounting of delayed rewards, in humans and non-humans alike, is best described by a hyperbolic function. One difference in findings from research on delay discounting in humans and non-humans is that humans have been shown to discount small rewards at higher rates than large reward. This is commonly referred to as the magnitude effect, and no such effect has been found in research with non-humans. Preference reversal is another phenomenon that has been established as an important process in delay discounting in both humans and non-humans. This refers to a reversal of preference from the smaller sooner reward to the larger later reward, as an equal delay is added to both alternatives. Scientists have suggested that preference for a smaller sooner alternative can be considered impulsive choice behavior, so that discount rates can be seen as a measure of impulsivity. Several studies have identified different variables that may affect individuals' discounting rates. For example, discounting rates tend to decrease with age. Also, people who are actively abusing drugs or alcohol discount delayed rewards at a higher rate that people who do not. Studies on delay discounting generate information related to socially important behavior and help asses clinical problems associated with impulsiveness.

Key words: discounting, delay, magnitude effect, preference reversal, addiction, impulsivity, discounting rates, discounting functions

If presented with a choice between an immediately available reward and an equal reward that can only be obtained after a certain time delay, people will generally prefer the immediately available reward (Green & Myerson, 2004). This might also be true in many situations where the later reward is of larger value than the immediate reward. Thus, it seems that delay to receipt of a reward has some effect on the perceived value of that reward. If someone is asked to choose between $10 today and $10 in a week, it is likely that the choice would fall on $10 today. If the reward available after one week was increased by $1, so that the choice was between $10 today and $11 in a week, many would still choose to receive $10 today. A preference for the $10 alternative indicates that $11 with a delay to receipt of one week is worth subjectively less than $10 received today (Green, Myerson & McFadden, 1997).

In everyday life, one is often faced with choices of performing responses that lead to immediate rewards or responses that lead to larger rewards that will only be received after a certain time. Take for example a student with a paper due the next day. This student might be faced with the choice of either staying home to write the paper, or going out to the movies with friends. Staying home might lead to handing in the paper on time and getting a good grade, but this reward will only be available some time after the choice is made. Choosing to go to the movies can result in a fun couple of hours with friends quite soon after the choice is made. Although the reward for staying home to finish the paper may in itself be perceived as larger than that for choosing to go to the movies, the student might well prefer to go out. Such a choice can be described as an example of delay discounting. The term delay discounting refers to a decrease in an outcomes value as a function of the delay between a response and the receipt of its outcome (Myerson, Green & Warusawitharana, 2001). If the student prefers to go to the movies rather than to work on the paper, this indicates that the value of the good grade-reward is discounted as a function of the delay to the receipt of such a reward.

Delay discounting is a factor in many decisions to be made in everyday life. One might choose between saving money or spending money, watching TV or preparing for next day's meeting, eating a doughnut or a healthy alternative and so on. All these examples include choices that in either case are unlikely to result in disastrous outcomes, but delay discounting can also characterize choices that might have great bearing in important aspects of a person's life. An area in which choices between smaller-sooner rewards and larger-later rewards have great importance is addiction. Addictive behavior can be seen as systematic preference for a smaller-sooner outcome rather than a larger-later one. For an alcoholic, choosing to have a drink can result in immediate relief from withdrawal symptoms. Choosing not to drink alcohol could lead to social acceptance, strengthening of family relationships and keeping a job. The reward for drinking alcohol is smaller, but immediate, while the reward of abstinence is larger, but temporally more distant. Research on the subject of delay discounting is important to achieve a better understanding of the process of decision making. Discovering variables that affect choices between smaller-sooner and larger-later rewards is of great interest and can affect most people, as we all participate in such decisions. Perhaps, even more importantly, such investigation might contribute to the understanding of addictive behavior and treatment for addicts whose behavior put them at risk.

Experiments on delay discounting often use adjusting-delay or adjusting-amount procedures (Reynolds, 2006). In adjusting-amount procedures the amount of the smaller-sooner reward is adjusted, so as to find the smallest amount of this reward that is preferred to the larger-later reward. This smaller-sooner reward amount is referred to as an indifferent point and represents the subjective value of the delayed reward (Odum and Rainaud, 2003). An indifference curve can be plotted by finding indifference points at several different delays (Petry, 2001). In an adjusting-delay procedure both the smaller-sooner (SS) and larger-later (LL) rewards are kept at a constant amount. The delay between response and reward for the

SS option is also kept constant, but the delay between response and reward for the LL option is adjusted. An example of this is a procedure with blocks of trials that include two free choices. In such a procedure two responses on the LL choice will lead to a set increase of delay in the LL option, while two responses on the SS choice will lead to an equivalent decrease (in the next block of trials). One response on each option (SS and LL) would result in the LL delay staying the same in the next block of trials. A mean LL delay is calculated once stability in this delay is reached (i.e. responses are distributed equally on the SS and LL option) and is referred to as an estimated indifference point (Mazur, 1988).

Reynolds (2006) refers to three different ways to experimentally measure delay discounting, hypothetical, real-reward and real-time. In experiments using hypothetical measures the participant chooses between rewards of different amounts or with different delays, but is never actually in contact with those rewards or delays. The participant is presented with questions, and asked to make a choice between two rewards of differing amounts and delays. Real-reward measures are similar to hypothetical measures, but include one real response choice, where the participants actually experience both the delay and reward. Which of the response choices that is to be experienced in reality, is randomly determined. In experiments with real-time measures the participant experiences all the contingencies (e.g. reward and delay from response to receipt of that reward). Most human research on delay discounting is conducted with hypothetical or real-reward measures. Both are less expensive and time consuming than using real-time measures. Non-human research on delay discounting, of course, relies on real-time measures. When real-time measures are used in delay-discounting research with human subjects, the rewards involved are usually of small amounts and the delays of shorter durations. Reynolds (2006) therefore states that such experiments are useful in studying delay discounting in terms of short time effects.

Several aspects of delay discounting have been investigated by a number of scientists. Firstly, a considerable amount of research has been conducted to determine which function; exponential or hyperbolic, best describes delay discounting. Estle, Green, Myerson, and Holt (2006) suggested that assumptions about the choice process may be derived from the functions used. It is therefore important that this subject is empirically investigated. With regard to discounting rates, research has been conducted both to determine the effect of reward amount and age. People have shown a tendency to reverse their choice between a smaller-sooner and larger-later reward, so that when both alternatives are temporally distant, the larger-later reward is preferred, but after a certain time, when the smaller-sooner reward is accessible relatively soon, the choice is reversed to a preference for the smaller sooner reward (Ainslie, 1975). This subject has also been investigated through empirical research. Also, some publications have focused on discussing and studying delay discounting as an operationalization of the terms impulsivity and self-control. Lastly a great volume of research has been dedicated to studying delay discounting in terms of addictive behavior. This article will discuss selected articles on each of the aforementioned subjects, with slightly more weight put on reviewing delay discounting and substance addiction.

Discussion

Different functions to describe delay discounting

Many scientists have focused research on determining the best mathematical equation to describe delay discounting. Economists usually favor an exponential function, assuming that a rewards subjective value has a fixed decrease over time:

$$V = Ae^{-bD}$$

Where V is the subjective value of the delayed reward, A is the amount of the reward, D is the time until its receipt and b is a parameter representing rate of discounting (Green & Myerson, 2004; Reynolds, 2006). Another alternative, preferred by many psychologists, is the hyperbolic equation:

$$V= A/(1 + kD)$$

As expressed in Green and Myerson (2004) V, A and D represent the same variables as in the exponential equation and *k* is a parameter that refers to the degree of discounting. Green, Frye and Myerson (1994) refer to Rachlin (1989) in suggesting an addition to this equation: raising the denominator to a power, ^{s}:

$$V= A/(1+kD)^{s}$$

According to Green, Fry *et al.* (1994, p. 33) ^{s} represents "the scaling of or sensitivity to delay". Myerson and Green (2004) further state that the value of ^{s} generally is equal to or smaller than 1.0. Several studies have concluded that hyperbolic equations are more successful in describing delay discounting than an exponential equation for example with regard to the importance of reward amount (Green, Myerson & McFadden, 1997) and preference reversal (Ainslie & Herrnstein, 1981), both of which will be further discussed later. One overlying reason why hyperbolic equations are often favored by psychologists is their basic assumption that the discounting of reward value due to delay results from the ratio of amount to delay, or the rate of reward (Myerson, Green & Warusawitharana, 2001; Green & Myerson, 1996). It has also been suggested that the value of a reward is discounted as a function of the time until its receipt because an increase in delay increases the possibility that something will happen to prevent the receipt of that reward, i.e. delay involves risk (Green, Fry, et al.,1994). The exponential equation is based on an assumption that the risk involved in delay to reward increases with fixed intervals per unit of time added to the delay. With regard to risk, a hyperbolic equation implies an assumption that the risk increase per unit of time added to the delay is greater in the beginning and gets progressively smaller as the delay gets longer. Exponential curves do not predict preference reversal, which is a factor that has contributed to several scientists proposing alternatives to this equation. Myerson et al. (2001) proposes area under the curve (AUC) as an additional, useful method for statistical analysis in comparing discounting data between groups or individuals. The formula for calculating AUC is :

$$(x_2-x_1)[(y_1+y_2)/2].$$

In the equation x_1 and x_2 are successive delays to receipt of reward while y_1 and y_2 are the discounted values associated with the current delays. To use the AUC measure the delay and discounted values must be presented as respectively proportions of the maximum delay and proportions of the undiscounted value, both ranging from 0.0 to 1.0. Each calculation with this equation makes up a trapezoid area on a graph and it is the sum of the areas of all the trapezoids that is termed the AUC. Steeper discounting is indicated by higher AUC values, while less steep discounting is indicated by lower AUC values. Myerson et al. (2001) further states that due to the use of normalized $_x$ and $_y$ values the value of the AUC will vary between 0.0 (steepest discounting) and 1.0 (no discounting).

Origin of research on delay discounting

Some of the earliest psychological studies on delay discounting were conducted by Chung (1965) and Chung and Herrnstein (1967). As stated by Chung (1965), previous research had shown that delays of reinforcement might hinder learning and acquisition of new behavior. Yet, his research is said to be the first to examine the effects of delays of reinforcement on rates of responding with previously learned behavior. Chung (1965) used pigeons to study the frequency of responding on a delay key with respect to the response frequency on a key that produced reinforcers immediately. The delays added between response on the delay key and production of the associated reinforcer varied between 0 and 28 seconds. It was found that as the delay was increased the relative frequency of responding decreased. Chung (1965) concluded that in addition to hindering learning, delay of reinforcement also reduces performance of learned responses. Chung (1965) refers to Herrnstein (1961) and Catania (1963) respectively in stating that frequency and amount of reinforcement is known to affect responding in a two-key choice situation, and goes on to propose that his findings argue for adding immediacy of reinforcement as a factor that affects choice in such a situation. Chung and Herrnstein (1967) conducted a similar experiment, but unlike Chung (1965), various delays were set for responses on both keys. In this procedure the delay on the standard key was set to 8 or 16 seconds and paired with a delay key for which the delay between response and reinforcer presentation was set between respectively 1 and 30 seconds or 2 and 30 seconds. For both conditions the results show a relatively steady decrease in relative frequency of responses on the delay key compared with responses on the standard key. Chung and Herrnstein (1967) expressed support for Chung's (1965) claim that immediacy of reinforcement should be added to the list of factors that affect responding in two-choice situations. Since these publications a considerable amount of research has been conducted on various aspects of delay discounting.

Magnitude effect

Many studies have shown that larger rewards are discounted less steeply than smaller rewards. For example, Green et al. (1997) used an adjusting amount procedure to examine whether amount of reward affected discounting rate. One of a series of larger later rewards, ranging from $100 to $100,000 and with delays ranging from 3 months to 20 years, was paired with a smaller sooner alternative that would range from 1% to 99% of the objective value of the larger later reward. For all pairings, the subjects (university students) were asked to choose the preferred alternative. Results show that discounting rates decreased with increase in reward amount. The discounting rate was although found to stabilize after $25,000, so that no further decrease was found as the reward amount was increased from $25,000 to $100,000. Green, Fry, et al. (1994) compared discount rates of various reward amounts with subjects from three different age groups. Myerson and Green (1995) reanalyzed the data obtained from this experiment with regard to the group of university student. Similarly to the procedure described in Green et al. (1997), the students were asked to choose between two alternatives, one larger later and one smaller sooner. The larger later alternative was constant at either $1000 or $ 10,000, while the smaller sooner alternative varied between 1% and 100% of the larger later alternative. The delays used varied from 1 week to 25 years. It was found that smaller later reward amounts were discounted more steeply than larger amounts, both on group level and individual level.

Myerson and Green (1995) discussed two possible explanations for the effect of amount on discounting rates. The first is in agreement with a psychologist view and has been termed the repeated choice model. According to this model discounting rates are directly influenced by the frequency of which a certain set of choices is likely to present itself. By this account, larger rewards are discounted at a lower rate, due to belief that opportunities to choose between larger rewards come less frequently than opportunities to choose between smaller rewards. The second theory is derived from an economist point of view and termed the expected value model. This perspective assumes that larger amounts are discounted less steeply because there is less risk associated with waiting for a larger reward than a smaller one. Green et al. (1997) refer to Green and Myerson (1996) in explaining how both ecological and cognitive risks associated with delay to receipt of reward might be lower for larger rewards. First, from an ecological point of view, if a reward is found by a competitor during the delay, it is more likely that some of the reward will still be left it the reward is larger rather than smaller. In addition, from a cognitive view in which risk connected with delay might represent risk of forgetting, a larger reward is said to be more easily remembered than a smaller delay. Green et al. (1997) express the need for further investigation of different explanations for amount-dependent discount rates. Specifically, they suggested that both risk and choice opportunities (involved respectively in the repeated choice and expected value models) could be explicitly manipulated in future experiments.

Human vs. non-human research

Results from research on delay discounting have shown many similarities between human and non-human subjects. Both human and non-human subjects have been shown to discount future rewards as a function of delay. In fact research with rats, pigeons (e.g. Mazur & Biondi, 2009) and monkeys (e.g. Freeman, Green, Myerson & Woolverton, 2009) have shown that the hyperbola-like function that best describes delay discounting in human subjects also provides a good description of the behavior shown by these non-human species. Despite many similarities, some differences have also been found between discounting in humans and non-human species. Firstly, research with non-humans has shown steeper discounting rates than with humans (Jimura, Myerson, Hilgard, Braver, & Green, 2009). Also, Studies with human subjects have, as mentioned, shown that larger rewards (up to a certain amount) are discounted less steeply than smaller rewards. This effect has not been found in non-human research. One such study was conducted by Green, Myerson, Holt, Slevin, and Estle (2004). In this study pigeon and rat subjects were used to study the effects of different reward amounts on discounting rates. An adjusting amount procedure was used to determine rates of discounting of 5, 12, 20, and 32 pellets with pigeons and 5, 12, and 20 pellets with rats. Each reward amount was tested with delay durations of 1, 2, 4, 8, 16, and 32 second. In addition to finding steeper discounting by the rats and pigeons than that reported from human research, it was also found that with these subjects, the rate of discounting was not systematically affected by the amount of the reward.

Several possible explanations for these findings, which differ from findings from similar experiments with humans such as those reviewed above, are discussed by Green et al. (2004). Firstly, a point is made that the reward amounts used in this experiment were smaller than amounts used in many studies with humans. On the other hand it is also pointed out that, although human studies of magnitude effects in delay discounting might have generally involved larger amounts, magnitude effects have also been shown when smaller amounts have been used. With reference to findings in human studies of stabilization of discounting rates at a certain level of reward amount, another possibility raised is that the smallest pellet amount used might represent reinforcement values of such high magnitudes that further amount increase would not affect discounting rates. Another suggestion refers to properties of the specific rewards used. Pellets (food) are essential for survival and might, as reinforcers, affect behavior differently than other types of reward, such as money which is often used in human studies. A third possibility is certainly that there might be certain differences between species that can account for different reactions to variations in reward amount. In that case, it will be of great importance to examine what exactly distinguishes humans from non-humans with regard to magnitude-effects on discounting rates. Green et al. (2004) argued against a suggestion that humans have different mental accounts for smaller amounts immediately available and larger delayed amounts, which explains the different results in research on magnitude effects with human and non-human subjects (Loewenstein & Thaler, 1989 as referred to by Green et al., 2004). Green et al. (2004) state firstly that two mental accounts (for smaller sooner and larger later rewards), in any case, would not suffice to explain the continuous decrease in discounting rates that have been found. Secondly Green et al.(2004) highlight findings of magnitude effects in delay discounting research with non-monetary rewards such as health and emphasize the unlikeliness that two different mental accounts for smaller and larger reward amounts, can explain such findings. One last suggestion made by Green et al. (2004) is that rule-governed behavior, which is of course limited to humans, might account for the differences of findings in human and non-human studies on magnitude effect on discounting rates. However, they emphasize that further research is necessary to determine the specifics of such a potential rule. Jimura et al. (2009) suggested that differences between human and non-human subjects with regard to steepness of discounting rates and presence of a magnitude effect might be attributed to differences within experimental procedures. Both the type of rewards used and the use of real-time measures in non-human research and hypothetical or real-reward measures in human research might affect the results. In their experiment, Jimura et al. (2009) used real-time measures with human subjects in an effort to make the procedure similar to that used with non-human subjects. Subjects were reported to have been mildly deprived of liquid, as the reward used was juice, lemonade or water (chosen by the participant). An adjusting-amount procedure was used where the subject was asked to choose between a smaller immediate reward and a larger-later reward. Subjective values of the delayed reward was a found by varying the amount of the immediate alternative at several delay durations ranging from 5 to 60 seconds. The results from this experiment showed that participants discounted delayed rewards at a considerably steeper rate than found in other human studies, bringing the discounting rate closer to that found in non-human research. On the other hand, the participants still showed magnitude effects, leaving that difference between humans and non-humans unchanged.

Preference reversal

When someone is faced with a decision between a smaller reward that will be received sooner and a larger reward that will be received later, the time, in respect to closeness to receipt of reward, at which the choice is presented, might affect their decision (Green, Fristoe,

& Myerson, 1994). For example if someone is asked to choose between $10 tomorrow or $100 in 3 months they might choose $10 dollars tomorrow, but if the same time delay is added to both options so that the choice is between $10 in 6 months and 1 day or $100 in 9 months, the choice might shift to that of the larger-later option of $100 in 9 months. Preference reversal as a function of equal delay increase to both SS and LL options has been confirmed by several studies. Ainslie and Herrnstein (1981) found that pigeons preferred a smaller immediate food reward over a larger food reward delayed by 4 seconds. This preference was shown to reverse as equal delays were added to both alternatives. Green, Fristoe, et al. (1994) presented undergraduate students with choices between a larger later hypothetical monetary reward and a smaller sooner one. The results from this study also demonstrate preference reversals. Preference shifted from the smaller-sooner alternative to the larger-later alternative as equal amounts of time were added before the receipt of both rewards. As mentioned the existence of such a process plays an important role in the discussion of what equation best describes delay discounting

Impulsivity and self-control

In behavioral science, impulsive behavior is often operationalized as the act of choosing a smaller sooner reward over a larger later reward (e.g. Madden, Petry, Badger, & Bickel,1997; Reynolds, 2006; Ainslie, 1975; Rachlin & Green 1972). It follows by such a definition that self-control can be operationalized as choosing a larger later alternative on the expense of smaller sooner one (Madden et al., 1997). Rachlin and Green (1972) suggest commitment of preference for a larger delayed reward as the model for self-control. Impulsiveness and self-control is in this sense closely related to preference reversal. When a choice between a smaller sooner and a larger later reward is made at a temporal distance from both alternatives, the larger later reward is likely to be chosen. However, this preference is often reversed if a choice of the two alternatives is to be made when the smaller sooner reward can be obtained immediately or at least in close proximity to the present, thus the term preference reversal. Commitment to the larger later choice, or self-control, can as such be dependent on avoiding a reversal of preference. To ensure receipt of the larger later reward, a commitment to this choice should be made at a point in time where this alternative bares higher value than the smaller sooner alternative (i.e., before preference reverses). An example of this, presented in Rachlin and Green (1972) is payroll savings. A person can make a choice to save a part of his monthly pay rather than to receive it at payday to spend. The commitment is made at a temporal distance from the actual payday and as a binding agreement cannot be broken at the time when the paycheck is due to be received. Thus a potential preference reversal that might have occurred close to payday is prevented.

Rachlin and Green (1972) investigated this subject through an experiment with pigeons. Pigeons were first presented with a choice of two keys. Twenty-five pecks were required to move to the next link, and the 25^{th} peck decided which key was chosen. Pecking the right key led to delay followed by illumination of two keys, red and green. Pecking the red key produced a smaller-sooner food reward, while pecking on the green key led to a larger food reward produced after a 4s delay. If the initial 25^{th} peck was on the left key, a delay was followed by illumination of only green key. Pecking on the green key led to a larger food reward after a 4s delay. In other words, at a temporal distance from the smaller-sooner alternative, pecking the left key committed the pigeon to the larger-later reward, because it ensured that the smaller-sooner alternative would not become available. Pecking the right key at this point lead to a new choice after a certain time at which he smaller-sooner reward was available immediately and the larger-later reward after a delay of 4s. The results from this experiment showed that the pigeons exclusively preferred the red key (smaller-sooner), when this was available together with the green key (larger-later). The larger-later reinforcement was only obtained through pecks on the left key in the initial stage. Increasing the initial delay led to a higher degree of preference for the larger-later reinforcement alternative. This shows that the smaller-sooner alternative was always chosen when it was immediately available, but that increasing the delay to both alternatives increased the rate of preference for the larger-later alternative which excluded further choice opportunities.

Ainslie (1975) uses the term specious to describe smaller-sooner rewards in relation to larger-later alternatives. This refers to the temporary attractiveness that a smaller-sooner reward is given by the its position in time, even though direct comparison of the two rewards in themselves might clearly show a greater value of the larger-later alternative. Children are generally considered to be more impulsive than adults. This was investigated through a discounting experiment conducted by Green, Fry, et al. (1994). The participants in the study were from three different age groups: sixth graders, college students and older adults. Through an adjusting amount procedure each groups discounting of delayed rewards were recorded and successfully described with a hyperbola-like function with the denominator raised to a power ^{s}. Results show differences between the age groups both with regard to discount rates and sensitivity to delay. The discounting rates were steeper from young adults to adults and children to young adults. In addition, the sensitivity to delay showed in the results indicate that the children were more sensitive to differences between short delays, while adults were more sensitive to differences between longer delays. As such, these results show that a decrease in impulsivity with age can be described through differences in discounting of delayed outcomes (Green, Fry et al., 1994).

Delay discounting and addiction

Research on delay discounting is especially important in understanding problematic and destructive behavior such as drug addiction and alcohol abuse. For an addict the immediate consequences of heroin injection can be feelings of intoxication and relief from withdrawal symptoms. The consequences of abstinence may be getting a job and being able to reestablish a relationship with family, but these larger-reward consequences are more temporally distant. Madden et al. (1997) suggested that substance abuse can be seen as impulsive behavior, in the sense that favoring the immediate consequence of drug consumption over the delayed consequences of abstinence reflects an impulsive choice. An explanation for continued drug abuse (i.e., a continuing preference for the smaller sooner reward of drug consumption rather than the larger later reward for abstinence) may be that the reward for abstinence is discounted as a result of delay to its receipt. It might therefor be assumed that people who struggle with drug or alcohol addiction discount delayed rewards at a higher rate than people who abstain from alcohol and drugs. As shown in a review of articles examining delay discounting with regard to addiction by Reynolds (2006), many studies have concluded that substance abusers do show greater rates of discounting than control subjects who are not substance abusers. A few such articles will be reviewed in the following section.

Madden et al. (1997) conducted an experiment with hypothetical measures of delay discounting to examine delay discounting with opioid-dependent subjects. They concluded that in comparison to the control group, the opioid-dependent participants discounted the value of the delayed reward at a significantly greater rate. Kirby and Petry (2004) compared discount rates of alcohol abusers, cocaine abusers, heroine abusers and a control group of non-substance-abusers. Their method involved real-reward measures of delay discounting in which there was a one in six chance that one of the 27 choices the participants made would result in actually receiving the chosen reward after the delay associated with that reward. The results of this experiment also showed a greater discount rate of future reward for the substance-abuse groups than for the control group.

Petry (2001) conducted an experiment that compared discount rates of money and alcohol. The results of this study showed that the alcoholic subjects had a greater discount rate of future rewards compared to non-alcoholic control subjects. Although a connection between substance abuse and higher discount rates of future rewards has been empirically established, a conclusion as to the cause and effect relationship is yet to be reached. Some research includes experiments that may shed light on the question of whether high discount rates are the cause or the effect of substance abuse.

Through their theory of rational addiction, Becker and Murphy (1988) claimed that higher discount rates of future rewards can be seen as a contributing cause of addiction. They suggested that substance abusers or persons struggling with other addictions have a high preference for the present, leading to higher discounting rates of delayed rewards. Further, they emphasized that this time preference (whether high or low) is stable, i.e. it is not malleable and therefore will not be affected by for example abstaining from drugs. One way to contribute to the understanding of the cause and effect relationship between discount rates and addiction is through investigation of differences in discount rates between currently using and currently abstinent addicts. In the aforementioned study by Kirby and Petry (2004) the participants who were substance abusers were also divided into one of two categories: currently active or currently abstinent: This allowed for an investigation of the possibility that discount rates might be affected by current abstinence in substance abusers. It was found that former heroin addicts, who currently abstained from drug use, had lower discount rates than currently using heroin addicts. This contradicts Becker and Murphy’s (1988) claim that time preference is stable. The fact that discount rates were shown to be different between former and active drug users points toward a conclusion that discount rates are malleable and therefor might perhaps be the effect of substance abuse rather than the cause of it. Petry’s (2001) study involved a comparison of discount rates of money and alcohol with subjects that were either currently active alcoholics, former alcoholics or had no prior history of any substance abuse. The method included both money and alcohol as rewards as well as both a larger ($1000 and

150 bottles of alcohol) and smaller ($100 and 15 bottles of alcohol) amount of the larger later option. A hypothetical measure of delay discounting where the subjects were asked to make a choice between two possible rewards was used to compare discount rates between the groups and between types and amount of reward. Results showed that the active alcoholics had higher discount rates of delayed rewards than the former alcoholics in three of the four comparisons.

Bretteville-Jensen (1999) conducted an experiment which compared discount rates of future reward with three groups of subjects: active substance abusers (of injections), non-substance abusers and former substance abusers. The purpose of the study was to empirically investigate the claims stated in the theory of rational addiction (Becker & Murphy, 1988). The three aforementioned groups were asked identical questions about what they would sell a hypothetical reward for today if the reward was to be received respectively one week from now and one year from now. The results show that the statements of choice from the group of active substance abusers imply a much greater discount rate for this group compared to the former substance abuse group and non-substance abuse group. The results from the former substance abuse group show a much smaller discount rate, but still somewhat greater than that of the non-substance abuse group. Bretteville-Jensen (1999) states that these results support the theory of rational addiction developed by Becker and Murphy (1988) only with regard to the fact that the active substance abusers reported higher discount rates than the non-substance abusers. On the other hand Bretteville-Jensen (1999) explicitly states that the results contradict a view of higher discount rates as a contributing cause of drug addiction, because the discount rates were not stable. In fact the discount rates seemed highly affected by abstinence from drug use.

Another investigation of factors that might be connected to drug addiction was conducted by Blondel, Lohéac and Rinaudo (2007). In their experiment, no significant difference in time preference was found between former heroin addicts and non-drug users. Aside from evidence of malleable discounting rates Bretteville-Jensen (1999) suggests some additional reasons why high discount rates might be considered to be effects of substance abuse. Withdrawal symptoms from abstinence might contribute to a preference for immediate rewards. Such symptoms can be painful and might add focus to the present rather than the future. In addition it is suggested that the life of a substance abuser might entail more risk for illness and even death, which then makes for a higher risk of not being able to receive a future reward. As a possible explanation for the somewhat higher discount rates in former substance abusers compared to non-substance abusers, Bretteville-Jensen (1999) suggests that some risk connected with substance-abuse might be long lasting and therefor also affecting discount rates even after abstinence is achieved. Madden et al. (1997) found a significant difference in discounting rates between the group of opioid dependent participants and the control group. The opioid dependent participants are although described as currently enrolled in treatment for their addiction and had been so for an average of 3.7 months. This indicates that in other experiments including both active and abstinent drug-addicts, this group of participants might have been categorized as abstinent. Therefore, the results reported in Madden et al. (1997) do not necessarily support assumptions that abstinence negatively affects discounting rates.

In their research Blondel et al. (2007) also focused on the role of willingness to take risks in addictive behavior, hypothesizing that drug users would have less aversion to risk compared to non-drug users. The procedure of the experiment involved answering 40 choice questions, half of which pertaining to time and half to risk. A hypothetical measure was used where, with regard to the risk portion of the questions, the participant was faced with 20 different choices between a riskier option with a higher maximum pay was paired with a less risky outcome with a lower maximum pay. One, randomly selected, reward was actually received by the participant. Results from this investigation confirmed the aforementioned hypothesis, showing a much higher aversion to risk among non-drug users than the group of drug-users.

Other aspects of this subject that have been investigated through experimental research are differences in discount rates between addicts of different substances and differences in discount rates of future monetary and substance rewards. Madden et al. (1997) found that opioid-dependent subjects discounted the value of future heroin rewards more steeply than that of monetary reward. These findings were supported by results from a similar experiment by Madden, Bickel and Jacobs (1999). Such high preferences for immediate heroin doses suggest that addicts might be willing to conduct dangerous behavior to acquire heroin sooner rather than later. Such behavior might include sharing injection needles and prostitution, which both can lead to contraction of serious diseases such as HIV and STD's (Madden et al., 1997). In the Madden et al. (1999) study, many participants indicated that withdrawal symptoms played an important role in their decisions between smaller-sooner and larger-later heroin alternatives. Both Madden et al. (1997) and Madden et al. (1999) refer to Navarick (1982) and Solnick, Kannenberg, Eckerman, and Waller (1980) when suggesting that negative reinforcement might cause a higher tendency for impulsive behavior than positive reinforcement. Because heroin injection is likely include negative reinforcement effects (escape from or avoidance of withdrawal symptoms) both Madden et al. (1997) and Madden et.al. (1999) present this as a possible explanation for the higher discount rates found with heroin rewards compared to monetary rewards. On the other hand, Petry (2001) reported higher discount rates of alcohol than money for both the alcoholic and non-alcoholic group. As it is highly unlikely that drinking alcohol is maintained by negative reinforcement in non-alcoholic subjects these findings contradict the previously stated claim that escape from withdrawal symptoms as a negative reinforcer might account for higher discounting rates of drugs and alcohol compared with money. Odum and Rainaud (2003) conducted a study specifically to further the understanding of why drugs of abuse are discounted at a steeper rate. Drugs and money are qualitatively different in many aspects. Odum & Rainaud (2003) suggest that whereas abused drugs can be considered as primary reinforcers, money is a generalized conditioned reinforcer. Also, drugs, in contrast to money, are directly consumable and while money is generally not devalued over delays, drugs can be seen as perishable goods. Another difference lies in the fact that excessive drug consumption might lead to satiation of that substance, while one is unlikely to be satiated with money (Odum & Rainaud, 2003). These features of drugs are shared with other reinforcers such as food. Therefore Odum and Rainaud (2003) compared discounting rates of alcohol, food and money with non-addicts, to investigate the possibility that food and alcohol might be discounted at similar rates, but steeper than money. Odum and Rainaud (2003) emphasize that to convincingly compare their results to findings in previous studies of differences in discounting rates between drugs and money the procedure used was developed to closely resemble those used in previous research. The results show that both food and alcohol were discounted more steeply than money, but with similar rates compared with each other. These findings suggest that steeper discounting of drugs might not be a separate process pertaining to drug-abuse, but a more general one found with both addicts and non-addicts that rests on specific features of the different reinforcers rather than their negative or positive reinforcement effects. By virtue of their results, Odum and Rainaud (2003 p. 312) propose that “primary/consumable reinforcers are discounted more steeply than conditioned/non-consumable reinforcers”.

On another note, Kirby and Petry (2004) concluded that with regard to addiction, the specific substance abused affected the discount rate. The results of their investigation showed that the heroin and cocaine abusers had higher discount rates than the alcoholics. The differences in discount rates between the alcoholics and the control subjects were, in fact, very small. Abstaining from drugs was also only shown to be connected with lower discount rates for heroin-addicts. No such difference was found between abstinent and currently using cocaine and alcohol addicts. Kirby and Petry (2004) suggested a few possible reasons why such an effect of abstinence was not found with the group of alcoholics and cocaine addicts. Firstly, with regard to the alcoholic group it is suggested that because the discount rate was so low, a floor effect might account for the lack of difference in discount rates between the actively using and currently abstinent alcoholics. Another possible explanation is that the abstinent heroin addicts had been in treatment significantly longer than the abstinent alcoholics and cocaine-addicts, and also had been abstinent for longer periods of time. Another question raised here is whether methadone, which is a commonly used in treatment of heroin addicts, might affect discount rates.

Research on addiction and delay discounting is not limited to human subjects. There have also been studies on the relationship between discount rates and addiction with non-human subjects. One such study was conducted by Woolverton, Myerson, and Green (2007). The subjects in this experiment were rhesus monkeys. The procedure involved choices between two levers that produced injection of cocaine through an intra-venous catheter. One lever produced an immediate injection of variable amounts of cocaine while the other produced a set amount of cocaine injected after variable delays. The results from this experiment showed that the value of the larger injection was discounted with added delay to its receipt and a hyperbolic discounting function accurately described the discounting of delayed cocaine injections. It was also found that increasing the amount of the immediate injection increased the frequency of which this alternative was chosen. Further, Woolverton et al. (2007) found that compared to other non-human research on this subject, the monkeys discounted the delayed cocaine injections at a relatively low rate. These results are reported to imply self-control on the monkeys' part, and contradict assumptions that drug abuse is always impulsive behavior. In an effort to contribute to the discussion on the cause and effect relationship between higher discounting rates and addiction, the monkeys' histories with self-administration of cocaine were examined with regard to their individual discounting rates. No connection was found between higher discounting rates and longer experience with cocaine injections. Woolverton et al. (2007) concluded that this is not consistent with an assumption that higher discounting rates of a certain drug is a result of previous experience with that drug i.e. that drug use causes higher discounting rates of that drug.

Research on the role of delay discounting in addictive behavior may be of great importance in reviewing and developing treatment models and preventive measures for addiction. Many studies have shown that substance-abusers display higher discounting rates than non-substance abusers. For this reason both Petry (2001) and Kirby and Petry (2004) suggested that treatments that focus on long-term consequences, whether those are reinforcers or punishers, may not be highly successful in treating substance addiction. An example of such consequences is methadone prescription, which will only be received after a relatively long period of abstinence and threats of incarceration or institutionalization that will only occur after a time. Higher discounting rates revealed with substance-abusers suggests that treatments that focus on smaller but more immediate consequences might be more effective. Again, both Petry (2001) and Kirby and Petry (2004) pointed to contingency management (Silverman, 2004) as an example of such treatments. In addition, behavioral procedures that focus directly on developing self-control are highlighted as possible effective treatments for substance abusers with higher discounting rates. With regard to possible effective treatments for drug addiction, Blondel et al. (2007) focus on their results which showed that drug-abusers had a much smaller aversion to risk than others without a history of addiction. They therefor suggested that effective treatments should refrain from focusing on uncertain consequences and rather, in contrast to suggestions by Petry (2001) and Kirby and Petry (2004), focus on more certain long term advantages of abstaining from drug use.

Many suggestions have also been made as to future research that can contribute to developing our understanding of drug-addiction. There is consensus that future research should focus on uncovering whether or not there is a cause and effect relationship between higher discounting rates and addiction, and further which of the two serves as a cause and which is the effect. One way of developing this understanding is suggested to be long-standing research on discounting rate, so that one might reveal whether higher discounting rates can be associated with future development of drug addiction (Madden, Bickel, & Jensen (1999). Kirby and Petry (2004) stated that an important subject for future research is to investigate the reasons why some abstinent drug addicts show lower discounting rates than active drug addicts. The effects of pharmacotherapy such as methadone treatment and experience with abstinence are suggested as specific variables that should be examined in terms of their effect on discounting rates (Kirby and Petry, 2004). Madden, Bickel, and Jacobs (1999) emphasized the importance of uncovering variables that might decrease discounting rates. Woolverton and Green (2007) highlighted the benefits of using non-human subjects in research on delay discounting and addiction. Non-human subjects allow for the use of real-time measures of actual drug injections. As mentioned, human research has shown that people tend to discount larger rewards at a higher rate than smaller rewards. It could be useful to examine whether similar results are found with monkeys and further, if this also is the case with drug rewards (Woolverton & Green, 2007). Lastly, Woolverton, and Green (2007) suggested that future research should also study differences in discounting rates of different types of drugs with regard to predictions of the likelihood of developing an addiction to those drugs.

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Effects of increasing, decreasing, and constant delays of reinforcement on choice behavior in rats

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Abstract

Delay discounting has been extensively studied with non-human subjects. Results from such research have proven effective in establishing general principles of delay discounting that further our understanding of the processes involved. The results from non-human studies are consistent with results from delay discounting studies with humans and can therefore provide a relevant basis for further investigations of delay discounting in humans. The current study investigated effects of different procedural arrangements on choice responses on a smaller sooner (SS) lever and a larger later (LL) lever in four Wistar rats. The delay preceding delivery of the LL reward was increased, decreased or kept constant within sessions. The delay duration was changed with a fixed increment contingent on one LL response. Results show that the percentage of LL responses generally decreased as the delay duration was increased. However, decreasing the delay did not result in increased percentage of LL responses and keeping the delay constant did not stabilize the percentage of LL responses. In fact the distribution of LL and SS responses was a great deal more similar than expected across all conditions. Results from delay discounting experiments may be affected by the order of conditions in the procedure. The results from the current study indicate that the contingencies implemented in later sessions of the experiment affected responding to a small degree. This highlights the need for further investigations that may contribute to accurately determine the variables that affect delay discounting as well as any effects that might result from the arrangement of the procedure such as the order in which conditions are implemented.

Key words: discounting, delay, choice, lever press, smaller sooner, larger later, order effects, rats, increasing delay, decreasing delay, constant delay, procedure

The term delay discounting refers to the decrease in present value of a consequence as a function of the delay until its receipt (e.g. Reynolds, 2006; Kirby & Petry, 2004; Green, Myerson & McFadden, 1997). A decrease in subjective reward value may also be seen as a decrease in that reward's effectiveness in controlling behavior (Reynolds, 2006). Both humans and animals are often faced with making choices between available alternatives. Behaving in accordance with one alternative might have different consequences than behaving according to another alternative and these consequences might also involve different delays. Research on delay discounting can generate knowledge about a wide variety of behavior that involves such choice (Woolverton, Myerson & Green, 2007). In fact Critchfield & and Kollins (2001) state that principles derived from delay discounting research can contribute to the understanding of any behavior that involves choices with delayed alternatives.

Much behavior which is considered problematic or anti-social involves choosing a smaller reward that can be received sooner over a larger reward that can only be received after a delay (Reynolds 2006). Drug use is one example of this. An addict's choice to inject heroin may be seen as choosing the smaller, but immediate reward of relief from withdrawal symptoms over larger rewards resulting from abstaining from drug use (Kirby & Petry, 2004). A number of studies have found correlations between addictive behaviors and higher delay discounting rates (e.g. Madden, Petry, Badger & Bickel, 1997; Petry, 2001). Ainslie (1975) proposes that the act of choosing a smaller reward over a larger one can be called impulsive behavior. Madden et al. (1997) further state that as an opposite, self-control choice refers to choosing a larger delayed reward at the cost of a smaller immediately available reward. Drug use and other harmful behaviors can by these definitions be seen as impulsive behavior (Madden et.al., 1997). Abstaining from such harmful behavior may depend on successfully implementing strategies to obstruct the sooner available reward's effectiveness in controlling this behavior (Ainslie, 1975; Rachlin & Green, 1972). Research on delay discounting can generate information valuable to investigations of helpful strategies and treatments of harmful impulsive behavior. Critchfield and Kollins (2001) suggest that delay discounting studies also may contribute to developing functional descriptions (rather than topographical) of psychological disorders by directing attention to the problems associated with the disorders. Laboratory procedures based on fundamental behavioral processes may serve to distinguish different populations (Critchfield & Kollins, 2001). Many studies, including Madden et al. (1997) and Kirby and Petry (2004), have found discounting rates to differ between various groups of people (e.g. heroin addicts and non-addicts). Critchfield and Kollins (2001) refer to such findings and suggest that studies on delay discounting may further research on clinical disorders that are typically associated with impulsive choices. ADHD and problematic behavior that is often expressed by people with this diagnosis are highlighted in this aspect.

Investigations of delay discounting in humans have some procedural limitations. Firstly, most such procedures involve hypothetical measures in which the participant is asked to make hypothetical choices. This does not allow the participant to actually experience the delay or the reward. In addition, the choices made are only reported verbally and the reported effects of the contingency manipulations are thus based on these verbal responses (Critchfield & Kollins, 2001). Barlow, Nock and Hersen (2009) state that self-reports often involve behavior that is difficult (or impossible) to observe by others. The information gathered through self-report measures can therefore not easily be verified. Secondly, many discounting curves established through research with humans are based on group data, and the models used cannot automatically be assumed to fit individual behavior (Critchfield & Kollins (2001). On the other hand, hypothetical measures in delay discounting procedures have been shown to generate similar results as procedures using real-time measures (Critchfield & Kollins, 2001; Reynolds, 2006) and the hyperbolic model has successfully been fitted to individual data (Critchfield & Kollins, 2001). Ainslie (1975) states that another concern with studies of delay discounting in humans is that other processes, such as cultural values, might affect observed outcomes. When delay discounting is investigated with non-human subjects this problem is assumed to be reduced. Using animal subjects also allows for stronger experimental manipulations and procedures with non-humans are based on real-time measures (Ainslie 1975). Critchfield and Kollins (2001) emphasize that finding from delay discounting research with non-humans correlate well with findings of delay discounting trends in humans. Through studies on delay discounting in non-humans, general principles can be (and have been) developed that may be implemented in human research to further our understanding of delay discounting processes (Ainslie 1975). In other words, research on delay discounting in non-humans is important to replicate and verify previous findings, to uncover new information about behavioral processes linked to delay discounting and to establish principles that can be further investigated in human research.

Delay discounting as a field of research has been extensively studied with non-human subjects. Chung (1965) reported that his study was the first to investigate the effects of delay on responding of previously learned behavior. In this study pigeons' pecking on two keys was reinforced. The delay between response and reinforcement on the delay key was varied irregularly between 0 and 28 seconds. Results from this experiment showed that frequency of responding on the delay key gradually decreased as the delay duration was increased. Since then, delay discounting experiments have been conducted with different animals and a variety of procedures. For example Rachlin and Green (1972) studied choices made by pigeons in a self-control perspective. The pigeons were introduced to a choice (Y) in which pecking the right key produced a delay of varied durations followed by a new choice situation (X) in which pecking a red key produced immediate access to a smaller food amount and pecking the green key produced a larger food amount after a 4 second delay. Pecking the left key in the initial choice situation (Y) produced the same delay duration followed by access to peck only the green light which again produced a 4 second delay before access to a larger food amount. Results from this experiment showed that when the pigeons were presented with a choice (X) of an immediate smaller reward and a larger reward delayed by 4 seconds, the pigeons preferred the smaller immediate reward. However the key preference in choice Y depended on the delay duration implemented in this condition. Smaller delay durations encouraged pecking on the key that led to choice X, while the pigeons pecked the key that ensured commitment to the larger reward when delay durations were longer. Ainslie & Herrnstein (1981) found that pigeons preference reversed from the smaller sooner (SS) alternative to the larger later (LL) alternative as a delay before the SS alternative was increased. They Woolverton et al. (2007) conducted an experiment to determine delay discounting of cocaine in rhesus monkeys and found that the preference for the frequency of preference for the SS alternative increased with an increase in amount. Further an added delay before the LL alternative decreased the rate of preference for this reward and discounting was well described by a hyperbolic function. Thirdly, Freeman, Green, Myerson & Woolverton (2009) studied delay discounting in rhesus monkeys using saccharin as reinforcers. Again the SS reward was gradually more preferred as the amount increased and the LL reward was gradually less preferred as the delay preceding its delivery was increased. Also in this study a hyperbolic function was found a good fit for the data. As a final example, Green, Myerson, Holt, Slevin, and Estle (2004) investigated the effect of reward amount on discounting rates in their experiment with rats and found that amount of reward did not significantly affect discounting rates.

Richards, Mitchell, De Wit and Seiden (1997) used an adjusting-amount procedure in which the delay conditions were varied every day to study discount functions in rats. They hypothesized that their results might be affected by a contrast effect. That is the order in which the experimental conditions were implemented might affect results. Richards et al. (1997) did, however, report that no contrast effects were found in their study. On a similar note Robles and Vargas (2008) suggested that procedural differences in delay discounting studies with humans might affect the amount of effort required in making choices. In their study Robles and Vargas (2008) found that results based on group data were affected by whether the choices were presented in descending or ascending order. Robles, Vargas and Bejarano (2009) studied the effects of order of choice presentation with a within-subject design with humans. Their results support those of Robles and Vargas (2008). Experience with prior contingencies may affect responding in a current condition. Although Richards et al. (1997) did not find that their results were affected by contrast effects, procedural order is a relevant issue in all delay discounting studies. In fact, when a certain condition (A) is followed by a second condition (B), the results obtained in condition B should only be judged as evidence of effects that follow from contingencies in condition B, when following condition A (Cooper, Heron & Heward). The order in which different conditions are presented in delay discounting experiments with animals is often varied between subjects (e.g. Green et al., 2004). However there seems to be a lack of direct investigations of the potential effects of procedural arrangements on results in delay discounting research with animals.

In any experiment it is essential to be able to identify the specific variables that affect behavior. In investigations concerning delay discounting, the preference of either a smaller sooner reward or a larger later reward is studied. It is possible that current contingencies in such studies are perceived differently by the participant according to their previous experience with conditions in the procedure. To enhance experimental control in delay discounting procedures it might be beneficial to study responding when the delay is decreased after the effects of increasing the delay have been established. Further, the contingencies might be reversed again to compare discounting with increasing delay before and after the subject had experience with another contingency (decreasing delay). To be able to revise delay discounting procedures, so that they may become increasingly effective in uncovering accurate effects of different delay contingencies, it is important to study how various contingencies affect responding. Research on delay discounting in rats and other animals typically involve adjusting-delay or adjusting amount procedures. Mazur (1988) described an adjusting-delay procedure in which the participants were exposed to choices between a standard alternative with a constant delay and reward amount, and an adjusting alternative with changing delay, but constant reward amount. The adjusting-amount procedure is described by Rachlin, Raineri and Cross (1991). The reward available after a delay and the duration of that delay were kept constant within each condition while the reward amount immediately available was changed. Both procedures aim to record indifference points at which the immediate reward is regarded as equally valuable as the delayed reward (Holt, Green & Myerson, 2012). Mazur (1988) states that delay discounting procedures with animals often are time consuming. Conditions are required to be in effect for a number of sessions on order to ensure stable responding on which inferences about indifferent points can be based.

The following experiment studied rats' responding on two levers that produced fixed smaller and larger reward amounts with an adjusting delay linked to the larger reward. The research aimed to investigate how rats' responding was affected by different delay contingencies conducted across various numbers of sessions. Responses were recorded with increasing, decreasing or constant delays preceding production of the larger reward. The delay duration on the Larger Later (LL) lever was increased or decreased by a fixed amount with every LL lever press within each session. The experiment did not aim to establish indifference points, but rather to study changes in choice behavior when the delay contingencies were continually changed throughout sessions. Indifference points are used to determine delay discounting functions (Reynolds, 2006; Holt et al., 2012). As the procedure in this experiment did not require stable responding before changing conditions or establish indifference points, no delay-discounting function could be used to present the results. Instead, the results were presented as percentage of LL responses in each block of trials. Responses on the LL lever should decrease as the delay duration is increased. Accordingly, responding in the LL lever should increase as the delay was decreased. When the delay was kept constant, the percentage of responses on the LL lever should stay more stable than in other sessions. However considerably fewer sessions were conducted with decreasing and constant delays, and the short time of experience with these contingencies might not prove effective in influencing the behavior considerably. Also, the starting delays in sessions with decreasing delay as well as the durations of the constant delays were varied. This allows for a comparison of how initial delays may affect behavior, and whether different constant delay durations generate a difference in the stability of responding. Thus, the main purposes of the present experiment were to investigate (1) how preference of reward was affected by continuous change in delay durations preceding delivery of a LL reward and (2) how the effects of increasing delay durations compared to effects of decreasing delay or keeping the delay duration constant.

Method

Subjects

Four experimentally naïve male Wistar albino rats were housed in transparent rooms of an animal colony. The room was kept at approximately 23 degrees Celsius and the light/dark cycle was 12 by 12 hours. The rats were water deprived for 22.5 hours before each session, then had free access to water for 30 minutes after each session and continually had free access to food. The rats were two weeks old when they were delivered to the laboratory. To ensure that the rats were in good health and growing at a normal speed, they were weighed every two weeks.

Apparatus

The experiment was conducted in the animal laboratory of the medical faculty at the University of Oslo (UIO) using two Campden (410-R) operant chambers. The chambers were approximately 21cm high, 25cm wide and 23cm deep and had aluminum walls and ceiling. There was a grid floor with steel bars and a drop tray beneath. The chambers were positioned inside sound-insulated boxes with ventilation. Inside the chambers there was a water dispenser on the left wall with a flap covering the hatch opening and a light inside that was lit for 0.5 seconds when reinforcement was produced. The water dispenser made a distinct sound when pumping water into the hatch and the standard amount of water produced was 0.03 ml. Two levers were placed either side of the water dispenser. Three light bulbs were positioned above the water dispenser and each lever. A light bulb in the ceiling was lit during all sessions as well as a LED light for the camera. As there were only two chambers available, each chamber was used by two subjects in successive sessions. In an effort to minimize the amount of new stimuli (such as smell), the subjects were exposed to in each session, there was a fixed order to which rat used the chamber first and second. Each chamber was connected to a computer, from which the experimental conditions were administered. The data generated in each session was recorded and saved on the computer.

Procedure

Each rat completed one session every day and all sessions lasted 30 minutes. The sessions were started approximately at the same hour each day. Table 1 shows the chronological order of procedural steps.

Magazine training.

After one session of habituation, four sessions of magazine training were conducted on a continuous reinforcement schedule (CRF) where reinforcement was contingent on the rats opening the magazine flap. This was followed by seven sessions of magazine training on a variable time schedule of 30 seconds (VT30). During magazine training both levers were retracted into the wall and only the house light was lit. The condition for moving from magazine training to the next step in the procedure was that the rats were observed to continually go to the tray and push open the hatch when the dispenser pumped water into the tray. Due to logistics it was necessary to move the experiment to new chambers after the 16th session. The water dispenser mechanism in these chambers made a different sound. Therefore, additional magazine training (four sessions) was necessary to again establish a connection between the sound of pumping water and the rats approaching the tray into which the water was pumped.

Shaping.

One session was conducted to shape lever pressing on the left lever and one to shape lever pressing on the right lever. In these sessions, only the left or right lever was available to press, while the other was retracted into the wall. Reinforcers were delivered manually by a remote control. Lever pressing was gradually shaped by administering reinforcers contingent on responses that were successively more and more approximate to the target response of pressing the lever. The two shaping sessions were followed by two similar sessions in which either the left or right lever was available, and lever presses were automatically reinforced according to a CRF schedule.

Lever presses.

Two additional sessions were conducted with only one lever available. The conditions during these sessions were identical to the previous sessions with automatically reinforced lever presses, except that the dispenser pumped two times the amount of water into the tray in the session where the left lever was available.

Preference tests.

Before moving on with the experimental stages of the procedure it was essential to ensure that the rats showed a preference for the larger water reinforcer. A series of sessions were conducted to test the preference of reinforcers. The criterion set for assuming preference of the larger water reinforce was that at least two thirds of the lever-press responses emitted were on the lever that produced the larger reinforcer across a minimum of three consecutive sessions. In the first session the ratio of water amount produced by lever presses was 1:2 on the right versus left lever. In the next two sessions the same ratio was 1:3. This was followed by seven sessions in which the ratio of the water produced by the right and left lever was 1:4. When the criterion for assuming preference was met, the ratio was switched to ensure that the preference was a result of the ratio of water amount and not due to for example the positions of the levers. Fifteen sessions were conducted with the ratio 4:1 of water produced by the left and right lever before stable preference for the larger reinforcer, in accordance with the criterion stated above, was established. In the last three of these sessions forced choice trials were introduced along with an intertrial interval (ITI). After a response in either lever both levers were retracted in to the wall and an ITI of 15 seconds was initiated. Every block of trials included six trials, the first two of which were forced choice. In forced choice trials only the left or right lever was available to press, while the other was retracted into the wall. Which lever was available in the first and second trial was randomized by the computer program. All following sessions were conducted with the same ITI and forced choice conditions.

Experimental sessions.

All responses emitted in the experimental sessions were recorded, but if all six trials in the final block were not completed, these responses were omitted in the processed results. The number of trials conducted within one session dependent on the amount of responses emitted by each rat, and might therefore be different for each rat.

Increasing Delay Conditions. In the sessions with increasing delay, each press on the left lever caused the delay between response (lever press) and reinforcement delivery (water pumped into the tray) to increase with a fixed time increment. The delay was set to 0s in the beginning of each session. Fifteen sessions were conducted with a delay increase of 0,4s per left lever press (Increasing Delay Condition 0.4s). Four sessions followed with a delay increase of 0.8s per left lever press (Increasing Delay Condition 0.8s).

Decreasing Delay Conditions. The conditions in the sessions conducted with decreasing delay were arranged so that the delay started at a specific duration and decreased by a fixed time increment with each press on the left lever. Two sessions were conducted in which the delay between lever press and response started at 6s and decreased by 0.4s with each press on the left lever (Decreasing Delay Condition 0.4s). The next session was conducted with a starting delay of 12s which decreased by 0.8s per left lever press (Decreasing Delay Condition 0.8s). In the final session conducted, the delay started at 15s and decreased by 1s with each press on the left lever (Decreasing Delay Condition 1s)

Constant Delay Conditions. Before the final delay decrease session, two sessions were conducted with fixed delay durations. One session was conducted with a fixed delay of 8s (Constant Delay Condition 8s) and two were conducted with a fixed delay of 12s (Constant Delay Condition 12s).

Results

The results from three rats show that the percentage of LL responses decreased as the delay to between LL response and LL reward increased. However the response patterns were in no way reversed as the contingencies were changed to that of decreasing delay and LL response percentages did not stabilize to any considerable extent when the delays were kept constant. The results are presented using percentage of responses on the LL lever in subsequent blocks of 4 free-choice trials. The blocks shown in the moving average graphs only include free choice trials. The delay duration, however, was affected by responding both in free choice and forced choice trials. The graph points in Figure 1.2, Figure2.2, Figure 3.2, Figure 4.2, Figure 5.2, Figure 6.2 and Figure 7.2 therefore represent the duration of delay in the last trial of a block. That is the maximum delay reached in that block of trials in Increasing Delay Conditions and the minimum delay reached in that block of trials in Decreasing Delay Conditions.

In most sessions, three of the four rats emitted fewer LL responses as the delay duration associated with this alternative was increased. With these three rats the decrease in percentage of LL responses was generally more marked in sessions with Increasing Delay Condition 0.8s (Figure 4.1) than in the previous sessions conducted with Increasing Delay Condition 0.4s (Figure 1.1, Figure 2.1 and Figure 3.1). Results from sessions completed by Rat 3901 show that the percentage of LL responses for the most part was high throughout the Increasing Delay Condition 0.4s sessions (Figure 1.1, Figure 2.1 and Figure 3.1). The percentage of LL responses did although decrease with the increasing delay in the Increasing Delay Condition 0.8s (Figure 4.1).

The results from sessions with Decreasing Delay Conditions were not as expected. Results from three of the four rats show that for the most part the percentage of LL responses decreased to various extents even as the delay duration decreased (Figure 5.1, Figure 6.1 and Figure 7.1). These figures show that Rat 3901, however, consistently responded with the same percentage of LL responses in the first and final block in all but one session, where the percentage of LL responses increased slightly.

Also Constant Delay Conditions had unexpected effects on responding. Figure 8 and Figure 9 show quite steep downward trends for three rats in sessions with these conditions.

Only with Rat 3901 was the percentage of LL responses quite stable in two of the sessions. A more detailed presentation of the results follows.

Increasing Delay Condition 0.4s

The procedure included fifteen sessions with Increasing Delay Condition 0.4s, but due to programming errors session 61 was not conducted with Rat 3901 and no data was recorder after the first block of trials in session 58 for Rat 3898. The percentage of LL responses in these sessions conducted with Increasing Delay Condition 0.4s are shown in Figure 1.1, Figure 2.1 and Figure 3.1. The delay contingencies resulting from LL responses in these sessions are shown in Figure 1.2, Figure 2.2 and Figure 3.2. Each figure includes results from five sessions in chronological order. The results from Rats 3898, 3899 and 3900 show that the percentage of LL responses for the most part decreased as the delay duration between response and reinforcement delivery increased. On the other hand, the results show that Rat 3901 continuously responded with high percentages of LL responses throughout these sessions. For Rat 3898 the graphs depicting data from the first five sessions with this condition (Figure 1.1) all show a decrease of minimum 50% in the percentage of LL responses between the first and last block within each sessions. Only two of the graphs from the second five sessions with Increasing Delay Condition 0.4s show such a decrease in percentage of B responses (Figure 2.1), while four of the last five sessions with this condition included a decrease of 50% or more in percentage of LL responses from the first to the last block in each session (Figure 3.1). Although the graphs show downward curve trends, most of the curves showing results from the sessions conducted with Increasing Delay Condition 0.4s have peaks, representing increases in the percentage of LL responses within the session. The highest delays recorded in the first (Figure 1.2), second (Figure 2.2) and last (Figure 3.2) five sessions conducted with this condition are respectively 6.4s to 10.8s, 6.8s to 9.2s, and 7.2s to10.4s.

Figure 1.1 shows that the percentage of LL responses emitted by Rat 3898 mostly stays between 50% and 100% in the first five sessions conducted with Increasing Delay Condition 0.4s (with the last block in session 49 as the only exception). The trends of the curves are downward in four of the five graphs. The first three graphs show a decrease percentage of LL responses of 50% from the first to the last block of trials. One graph shows a 25% decrease, and in the last graph the percentage of LL responses is the same in the first and final block. The highest delays reached in these five sessions were between 7.6s and 10.4s (Figure 1.2). The results shown in Figure 2.1 show more variation in percentage of LL responses. The graphs in Figure 2.1 all show downward curve trends, showing a minimum decrease of 50% in percentage of LL responses from the first to the last block in four out of five sessions. The percentage of LL responses in the last block is, although, consistently either higher or equal to the percentage of LL responses in the previous block. Even though there is, as mentioned, clear downward curve trends in the graphs from all five sessions, most sessions include an increase in percentage of B responses, showing as peaks in the curves. The maximum delay reached in each session is shown to be between 8.8s and 10s (Figure 2.2). The curves representing the percentage of LL responses in the last five sessions conducted with Increasing Delay Condition 0.4s with Rat 3899, shown in Figure 1.3, also have downward trends. The curves in three of the graphs are quite stable, while the curve representing data from session 61 is more jagged. The percentage of LL responses in session 61 is shown to be repetitively decreasing and increasing, reaching 50% already in the second block at a delay maximum of 2.8s. The maximum delays shown in each session range from 7.6s to 11.2s (Figure 3.2).

The results from the first and second five sessions with Increasing Delay Condition 0.4s conducted with Rat 3900, as shown in Figure 1.1 and 2.1, are similar. Most graphs show a downward trend to some extent, but in only four of the ten sessions did the percentage of LL responses decrease by 50% or more from the first to the final block of trials. The highest delays reached vary from 10.4s to 13.6s in Figure 1.2 and from 10.8s to 12.8s in Figure 2.2. The graphs in Figure 3.1 all show more stable downward trends for Rat 3900. The amount of LL responses decreased by 50% from the first to the last block in all sessions. The maximum delay duration reached in each session is between 11.2s and12.8s (Figure 3.2)

The percentage of LL responses did not go below 50% in any of the fourteen sessions conducted with Increasing Delay Condition 0.4s with Rat 3901. Neither was there a decrease of 50% between the first and last block of trials, with respect to amount of LL responses, in any session (Figure 1.1, Figure 2.1 and Figure 3.1). Nine out of the fourteen sessions do although include a 25% decrease in percentage of LL responses between the first and last block. There is, as such, a slight downward trend in nine sessions, but not in the remaining five sessions. The percentage of LL responses was consistently higher than 50% in all but 4 sessions. The highest delays reached ranged from 9.2s to 11.2, 9.2s to 13.2s and 10.8s to 11.6s in the first (Figure 1.2), second (Figure 2.2) and last (Figure 3.2) block of five sessions respectively.

Increasing Delay Condition 0.8s

All four rats completed four sessions with Increasing Delay Condition 0.8s. Results from these sessions show that the percentage of LL responses generally decreased more steadily or marked in these sessions compared to previous sessions with Increase Condition 0.4s (Figure 4.1). The graphs representing results from Rat 2898 show quite stable downward trends. Each curve has one peak of increase in percentage of LL responses, but otherwise show a decrease or no change in LL response percentage from one block to the next. All graphs show that the percentage of LL responses decreased with 75% from the first block of trials to the last. The highest delay duration reached within each session ranges from 17.6s to 23.2s (Figure 4.2).

The graph curves representing Rat 3898's LL responses in Figure 2 also have relatively steep downward trends. The curves all have peaks, showing an increase in percentage of LL responses from one block to the next, but are still considered quite stable. The graphs show that the percentage of LL responses decreased by a minimum of 50% from the first to the last block in each of the four sessions. In fact, in three of the four sessions the percentage of LL responses is shown to have decreased by 75% from the first to the last block of trials. The maximum delay duration reached within the sessions ranges from 17.6 to 20.8s (Figure 4.2).

The results from Rat 3900 also show that the percentage of LL responses decreased as the delay durations increased, and three of the four graphs show a decrease of 50% or more in amount of LL responses from the first to the last block. The highest delays reached in each session ranges from 23.2s to 25.6s (Figure 4.2).

The graphs in Figure 4.1 show downward trends also for Rat 3901, although the decreases in LL responses were not as steep as with the other rats. In two sessions the amount of LL responses decreased by 50% or more from the first to the last block, while there was a 25% decrease in amount of LL responses from the first to the last block in the two other sessions. The highest delays reached in these sessions are between 15.2s and 20s (Figure 4.2).

Decreasing Delay Condition 0.4s

Percentage of LL responses in the two sessions conducted with Decreasing Delay Condition 0.4s is shown in Figure 5.1. The graph curves representing data from Rat 3898 show that the percentage of LL responses is consistently high throughout both sessions, ranging from 100% to 50% in Session 67 and 75% and 50% in Session 68. In Session 67 there is a slight decrease in percentage of LL responses from the first to the last block. The percentage starts at 100% in the first block and decreases to 75% in the last. In Session 68 the percentage of LL responses is 75% in both the first and the last block. The percentage of B responses in the blocks in which the delay duration has decreased to 0s ranges from 50% to 100% in session 67 and 75% to 100% in session 68.

The curves representing responses from Rat 3899 in Figure 5.1 have downward trends. Both include two peaks, but are otherwise stable. The curve representing data from Session 67 shows a consistent percentage of LL responses in at 25% for the final four blocks of this session. The percentage of B responses in the blocks in which the delay duration has decreased to 0s ranges from 0% to 100%.

These graph curves in Figure5.1 representing data from Rat 3900 are both very jagged. The percentage of LL responses increased and decreased multiple times. In Session 67, the amount of LL responses varied between 100% and 0% within the session, but the percentage of LL responses only decreased by 25% from the first to the final block. In Session 68 the amount of LL responses varied mostly between 100% and 75% within the session. In both the first and the final block the amount of LL responses was 75%. The blocks in which the delay duration had reached 0s included LL response percentages between 0% and 100% in session 67 and between 50% and 100% in session 68.

The percentages of Rat 3901’s LL responses were at the same value in the first and the final block in the sessions shown in Figure 5.1. The graph curves are quite jagged, showing a continuous change in LL response percentage between blocks of trials. The percentage of LL responses ranges between 75% and 100% in the blocks where the delay duration was 0s in session 67 and between 50% and 100% in session 68.

Decreasing Delay Condition 0.8s

Only one session was conducted with Decreasing Delay Condition 0.8s. Figure 6.1shows the percentages of B responses in this session. The graph curve for results with Rat

3898 has a downward trend, starting with LL responses at 100% in the first block and decreasing to 25% in the last. After the delay reached 0s the percentage of LL responses in the following blocks ranged from 25% to 75%.

The curve representing the data from Rat 3899 is also slightly downward in trend, but less so than the curve showing the results from the previous two sessions. The curve is also less stable, showing more peaks in LL response percentages. The percentage of LL responses decreased from 75% to 50 % from the first to the last block. The percentages of LL responses shown in the blocks in between do although vary from 100% to 0%. The percentage of LL responses in the blocks with 0s delays varied between 0% and 100%.

In Figure 6.1 the graph the curve representing percentage of LL responses by Rat 3900 is constant at 100% the first 3 blocks and then has a steady downward trend, with only one peak. The amount of LL responses decreased from 100% to 25% from the first to the last block. The percentage of B responses in the blocks in which the delay durations were 0s range from 25% to 100%.

For Rat 3901 the results show that the percentages of LL responses were at the same value in the first and the final block in Session 69 (Figure 6.1) LL responses were consistently at 100%, with only one block as an exception. In the blocks with delays of 0s, the percentage of LL responses was 100%.

Decreasing Delay Condition 1s

Results from the session conducted with Decreasing Delay Condition 1s are shown in Figure 7.1 and Figure 7.2. Figure 7.1 shows that the curve for Rat 3898 has a downward trend, starting with LL responses at 100% in the first block and decreasing to 25% in the last. The Percentage of LL responses after the delay had decreased to 0s varied between 0% and 100%.

For Rat 3899 the percentage of LL responses was 50% in the first block, at a minimum delay of 12s, but then decreased to 25% in the second and varied between 25% and 0% in all subsequent blocks. The lowest delay duration reached in this session for Rat 3899 was 3s (Figure 7.2).

Figure 7.1 shows that the amount of LL responses in Rat 3900 was constant at 100% in the first blocks. It then decreased, increased and decreased again. From the first to last block of trials the amount of LL responses decreased from 100% to 50%. The delay duration decreased to 0s in the third block, and the percentage of LL responses in subsequent blocks varied between 100% and 50%.

The curve in Figure 7.1 that represents Rat 3901's responses has a slight upward trend. The percentage of LL responses decreased in the middle blocks, but then increased again toward the final blocks of trials. There was a 25% increase in amount of LL responses between the first and the last block. The delay duration only decreased to 0s in the second last block, and the percentage of LL responses in this and the final block were 100% and 75%

Constant Delay Condition 8s

One session was conducted with Constant Delay Condition 0.8s. The rats' responses, in terms of percentage of LL responses, from this session are shown in figure 8. The curve showing data from Rat 3898 has a steep and smooth downward trend. The percentage of LL responses decreased steadily from the third to the last block. The percentage of LL responses started at 100% in the first block and decreased to 0% in the final block.

The results from Rat 3899 also show a decrease in percentage of LL responses from the beginning to the end of the session. In the first block the percentage of LL responses was 75%, while it decreased to 25% in the final block.

The curve representing percentage of LL responses in Rat 3900 also has a downward trend. Figure 8 shows that the percentage of LL responses was constant at 100% in the first blocks, then decreased to 25% and increased to 50% in the next few blocks before the final block, in which the percentage of B responses was 25%. On the other hand Figure 8 also shows that the percentage of LL responses emitted by Rat 3901 was quite stable between 75% and 100%

Constant Delay Condition 12s

Results from the two session conducted with Constant Delay Condition 12s are shown in Figure 9. The curves representing data from Rat 3898 have downward, but slightly jagged trends. Both curves show 100% LL responses in the first block, while the percentage of LL responses decreased to 0% and 25% in the final blocks of Session 71 and Session 72 respectively.

The results from sessions conducted with Rat 3899 also show a decrease in percentage of LL responses from the first to the last block in each session with Constant Delay Condition 12s (Figure 9). The graphs show that the percentages of LL responses were high in the first blocks of each session and decreased to 0% toward the final blocks. However the percentage of LL responses increased to 50% in the final block in Session 71.

Rat 3900 responded 100% according to the LL alternative in the first block of both sessions. In Session 71 the percentage of LL responses gradually decreased to 0% by the final block, while the percentage of LL responses in Session 72 stayed between 100% and 50%.

Figure 9 shows that Rat 3901 almost exclusively emitted LL responses in session 71. The percentage of LL response was 100% in all blocks except one, where the percentage decreased to 50%. The results from the second session conducted with this condition show a decreasing trend with regard to LL response percentage, decreasing from 75% to 0% from the first to the last block of trials.

Discussion

This study aimed, firstly, to investigate how gradual change in delay durations affect responding in a choice situation between a smaller sooner (SS) reward and a LL reward. When a less valuable, but sooner available reward is preferred to a larger delayed reward, the value of the larger delayed reward can be said to have been discounted (Reynolds, 2006). As the delay to receipt of reward LL was increased, the amount of LL responses generally decreased with three of the rats, indicating that the value of the LL reward was discounted as a function of the duration of time to its receipt. These results offer support for findings that rats gradually decrease their preference for a larger reward as the delay preceding the receipt of this reward increases. Similar findings are consistent in delay discounting literature (e.g. Chung, 1965; Chung & Herrnstein; 1967; Rachlin & Green, 1972; Ainslie &Herrnstein, 1981). The results from this study show a decrease in percentage of LL responses within sessions already from the first sessions conducted with Increasing Delay Conditions. This decrease was although more marked and stable in the sessions with Increasing Delay Condition 0.8s than in the previous sessions. That is, after the rats had completed previous sessions where they were exposed to the existing contingencies. This could indicate differences in how larger and smaller delay increase increments affect choice, but may also simply be a result of extended experience with delay increase contingencies in general. With some of the rats, the decrease in percentage of LL responses became more apparent in later sessions with Increasing Delay Condition 0.4s as well. This indicates support for a theory that active contingencies may become more effective in influencing behavior after extended exposure to these contingencies.

A second goal for this study was to investigate how the effects of increasing delay durations compared to effects of gradually decreasing the delay duration or keeping it constant. When the delay contingencies were reversed so that the time to receipt of the LL reward was gradually decreased with every LL response one could hypothesize that the percentage of LL responses would increase rather than decrease within the sessions. Such an effect was not found in this experiment. The results from the sessions conducted with Decreasing Delay Conditions show that the percentage of LL responses for the most part decreased within the sessions. In some cases the percentage of LL responses was unchanged from the first to the last block. In only one session, with Rat 3901, was there a slight increase in LL responses from the first to the last block. In other words the distribution of the rats' responses was much like what would be expected if the delay durations were in fact increasing rather than decreasing. Again the results from 3901 show responding that differs from that recorded with the other rats. In fact Rat 3901 was the only rat to show an increase in percentage of LL responses (in accordance with expected results) in one of the Decreasing Delay Condition sessions. In the other two sessions the percentage of LL responses were equal in the first and last block.

Richards et al. (1997) found that the order in which different delay contingencies were tested with rats did not affect results. Mazur (1988) varied four different variables in an adjusting delay procedure with pigeons, but did not find that this affected results (indifferent points) to any considerable degree. The contingencies involved in the Increasing Delay Conditions and Decreasing Delay Conditions are opposite, while various the conditions tested in Richards et al. (1997) and Mazur (1988) are much more similar. The results from the Decreasing Delay Conditions in this study suggest that experience with previous conditions can greatly affect rats' responding when a newly introduced condition is highly different from the previous condition. Although the arranged contingencies in the Increasing Delay

Conditions seemed to affect responding soon after their implementation, it might take longer for opposite contingencies to be established as effective in influencing behavior. Distribution of responses on the SS and LL lever might have changed with extended exposure to the Decreasing Delay Conditions.

The effects of the active contingencies on responding in the sessions conducted with Constant Delay Conditions also differed from expected results. With three of the rats the percentage of LL responses decreased markedly from the beginning to the end of most sessions. The percentage of LL responses was also consistently high (100% or 75%) in the first block of each session. Rat 3901, on the other hand, responded in accordance with a quite stable preference for the LL reward in two of these three sessions. It was hypothesized that constant delay durations would result in more stable percentages of LL responses. This is true for two of the Constant Delay Condition sessions with Rat 3901. However the percentage of LL responses in the successive blocks is higher than what might be expected when comparing the percentage of LL responses at these delays in the Increasing Delay Conditions.

Increases and decreases in the delay durations were directly linked to responding. Although higher delay durations were assumed to generate fewer LL responses, a decrease in the delay duration was made contingent on responding on the LL lever, so that theoretically high LL response rates might be reinforced by a decrease in delay duration. In such a case the constant delay contingencies might be experienced as extinction of the delay decrease reward. In the Constant Delay Conditions the rats generally responded with a higher percentage of LL responses in the beginning of the session. The percentage of LL responses then decreased with time. This might be a result of responding not having the effect on delay duration that it had in previous sessions.

The delays recorded not account for any additional time have elapsed between production of water and the rats contact with the water. The rats might therefore have experienced different delays than those recorder if they did not always go directly to the tray when the water was produced. Also, the delay durations in the Increasing Delay Condition 0.8s and Decreasing Delay Condition 1s were, at times, higher than 15 seconds. As a result the ITI interval of 15 seconds was not sufficient to ensure that every trial lasted the same amount of time independent of which lever was pressed. In other words, choosing to respond on the LL lever affected the trial duration as well as the delay variable. To minimize influence of other factors than the experimental variable, the ITI should be arranged so that it is always longer than any delay duration connected to the LL option.

Rachlin (2006) states that wide differences in discounting rates can be found between individuals. Richards et al. (1997) reported differences in the steepness of the discount functions between the individual rats in their research. Myerson & Green (1995) also highlighted individual differences in discounted values of money in human participants. Individual differences in results from delay discounting research are not uncommon. In this study the most notable differences were seen between Rat 3901 and the other rats. In the sessions conducted with Increasing Delay Conditions it seemed that the contingencies had to be in effect for a longer time (in more sessions) before the effect on Rat 3901’s responses were increased. As such, it might be that this rat simply was less aware of the acting contingencies. In the Constant Delay Conditions however, the fixed delay durations seemed to affect the behavior of Rat 3901 in a manner that was closer to what was expected that the behavior shown by the other rats. This might suggest that Rat 3901’s behavior was more clearly affected by to the contingencies in later sessions, after having more exposure to the experimental setting.

Research on delay discounting may contribute to understanding of a variety of behavioral patterns. Studies involving non-human subjects can be effective in determining behavioral processes that are important for further studies of human and non-human delay discounting. It is imperative that experimental research be able to effectively distinguish controlling variables in delay discounting studies. Therefore further investigations that contribute to developing and revising effective delay discounting procedures are of great importance. The current study has shown that participants' extent of experience with different conditions can affect responding. It has also made clear that behavioral patterns can be difficult to reverse with a reversal of contingencies in a delay discounting procedure.

To further investigate how variations in delay durations affect responding it would be useful to arrange the condition so that changes in delay duration are not contingent on responding on the LL lever. For example, if the changes in the delay duration were contingent on both SS and LL responses differential effects, other than the experimental variable of delay duration, of responding on the two levers would be decreased. Alternatively, changes in the delay durations could be made time contingent, so that the delay increased or decreased with fixed intervals per a certain unit of time. It would also be useful to extend the number of sessions conducted with this condition. Although, a reversal of contingencies can be effective in establishing experimental control, the results from this study has shown that responding in this delay discounting procedure could not easily or quickly be altered or reversed. Arranging the procedure so that stable responding is ensured before changing conditions, may generate more stable results and improve the effect of delay contingencies on responding.

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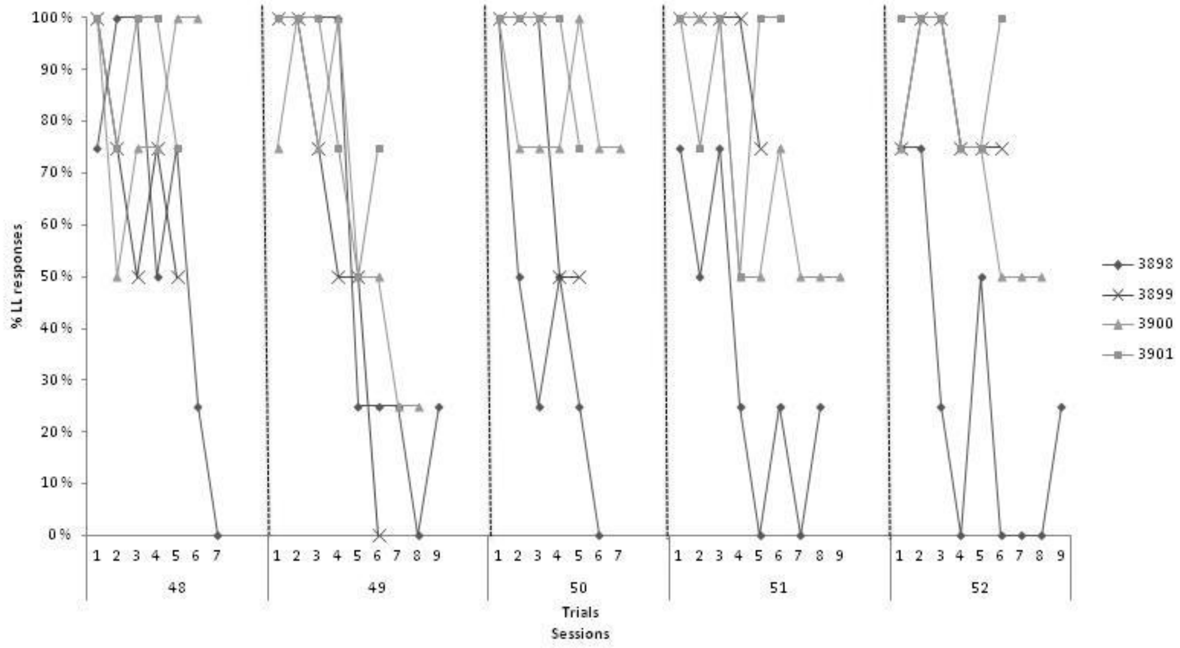

Figure 1.1. Percentage of LL responses in sessions with Increasing Delay Condition 0.4s. Each data point represents the percentage of LL responses in one block four free-choice trials

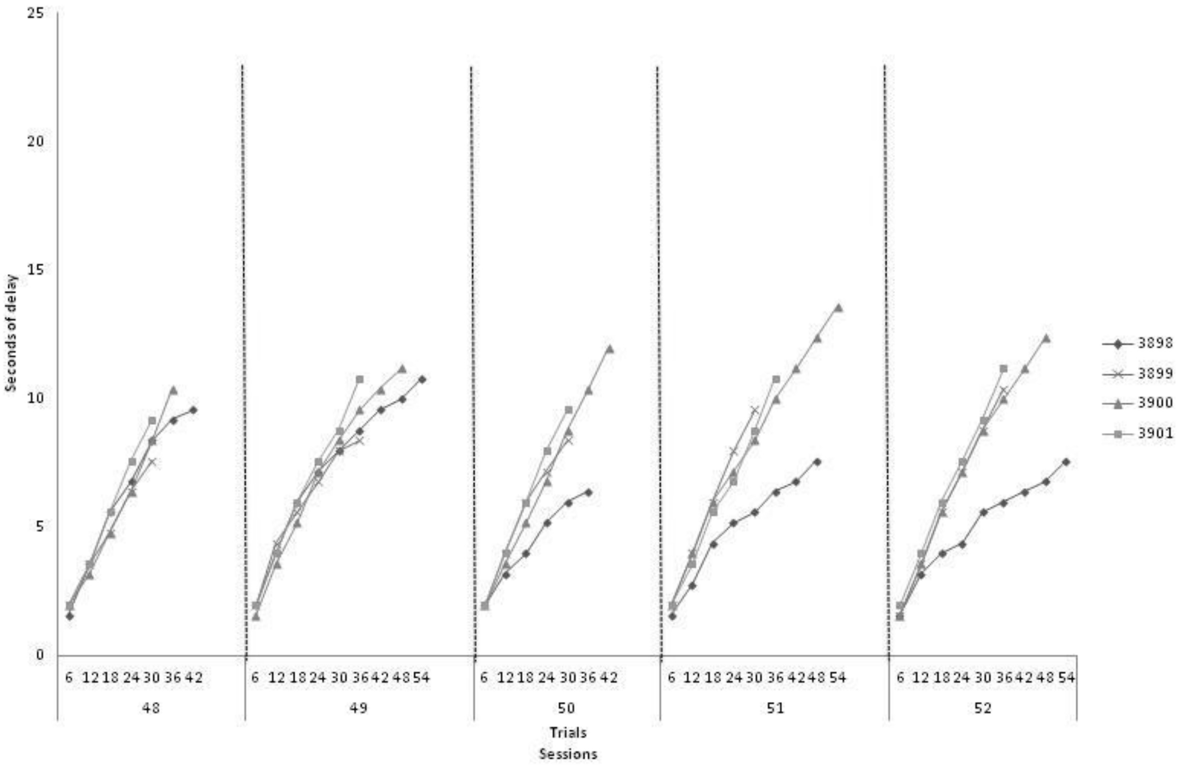

Figure 1.2. Delay contingenciencies linked to LL responses in the last trial of each block in sessions with Increasing Delay Condition 0.4s.

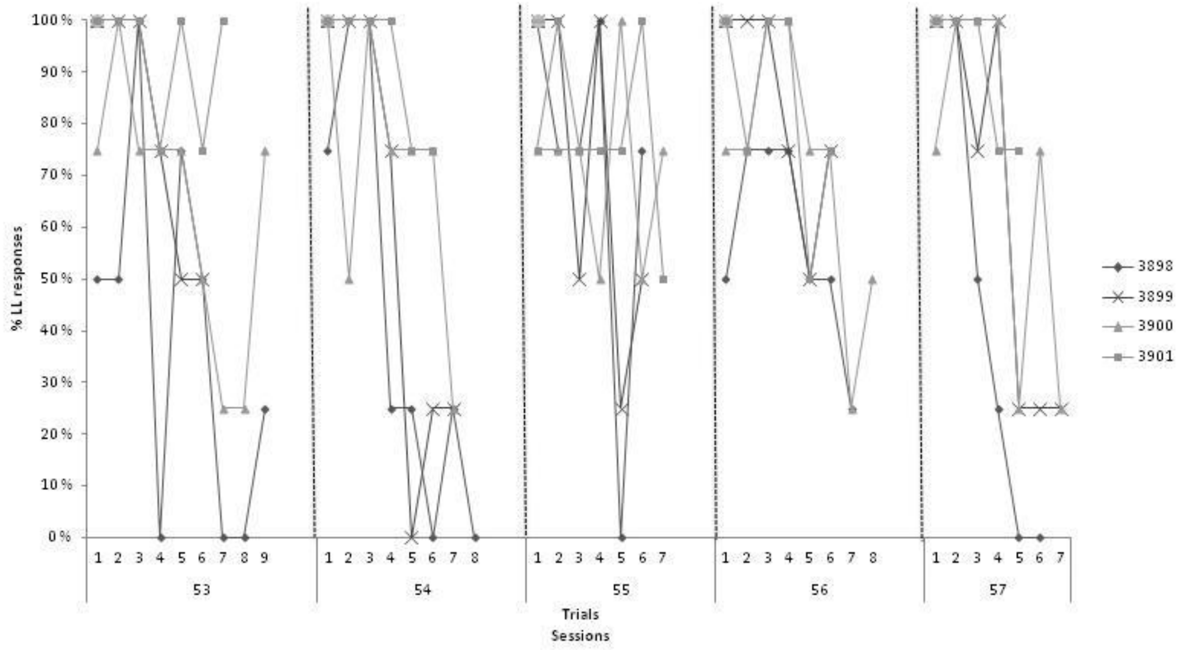

Figure 2.1. Percentage of LL responses in sessions with Increasing Delay Condition 0.4s. Each data point represents the percentage of LL responses in one block four free-choice trials

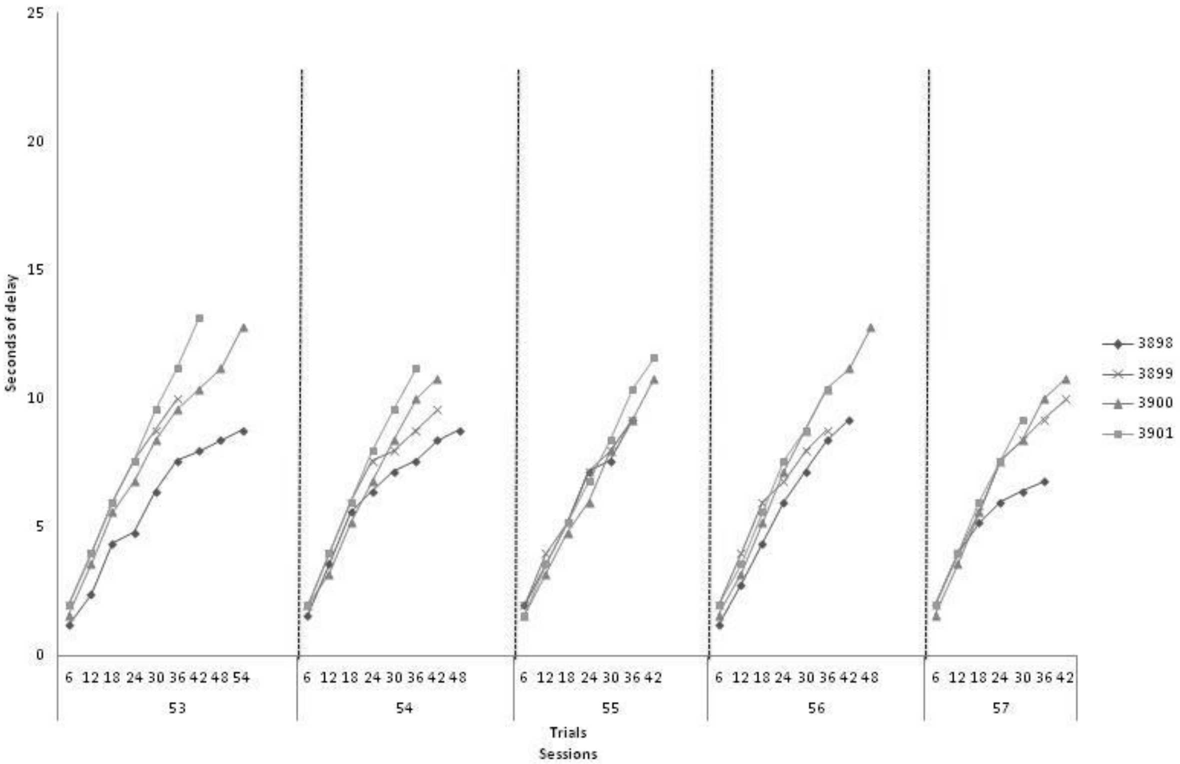

Figure 2.2. Delay contingenciencies linked to LL responses in the last trial of each block in sessions with Increasing Delay Condition 0.4s.

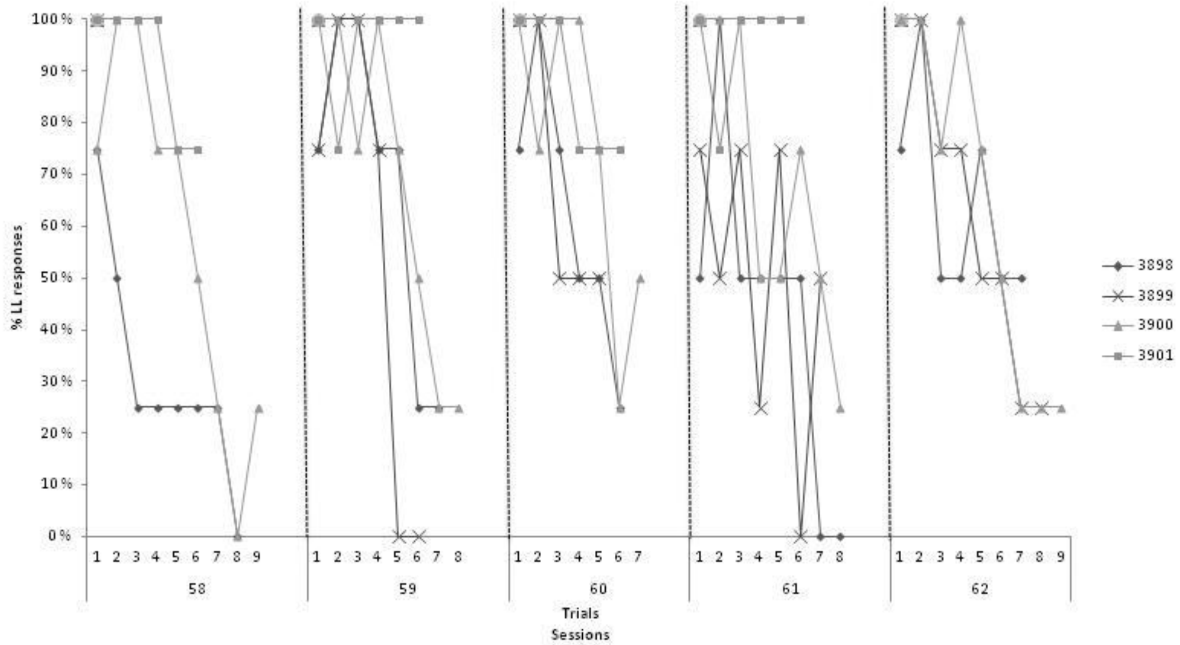

Figure 3.1. Percentage of LL responses in sessions with Increasing Delay Condition 0.4s. Each data point represents the percentage of LL responses in one block four free-choice trials.

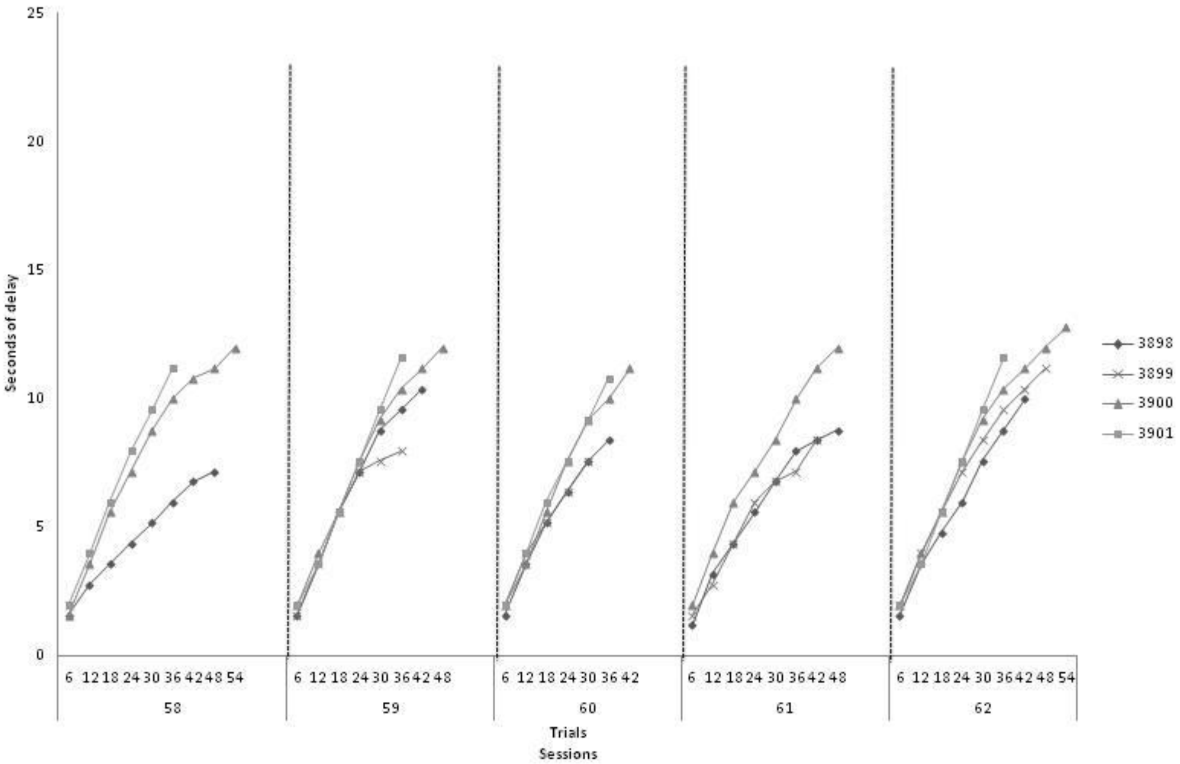

Figure 3.2. Delay contingenciencies linked to LL responses in the last trial of each block in sessions with Increasing Delay Condition 0.4s.

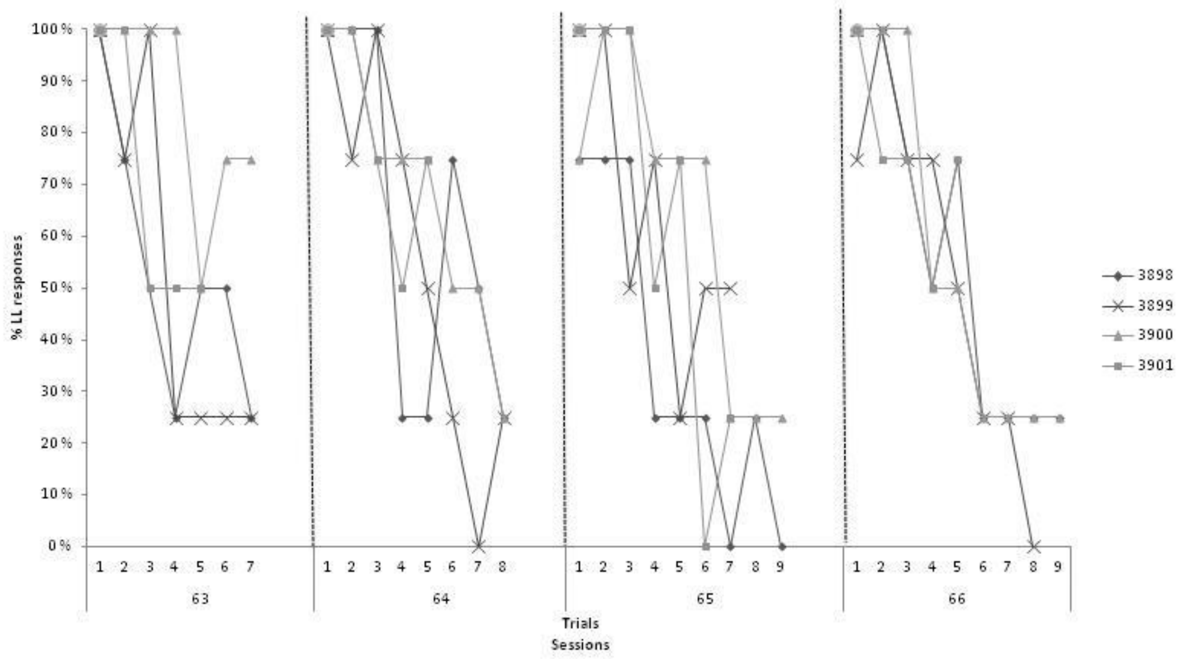

Figure 4.1. Percentage of LL responses in sessions with Increasing Delay Condition 0.8s. Each data point represents the percentage of LL responses in one block four free-choice trials

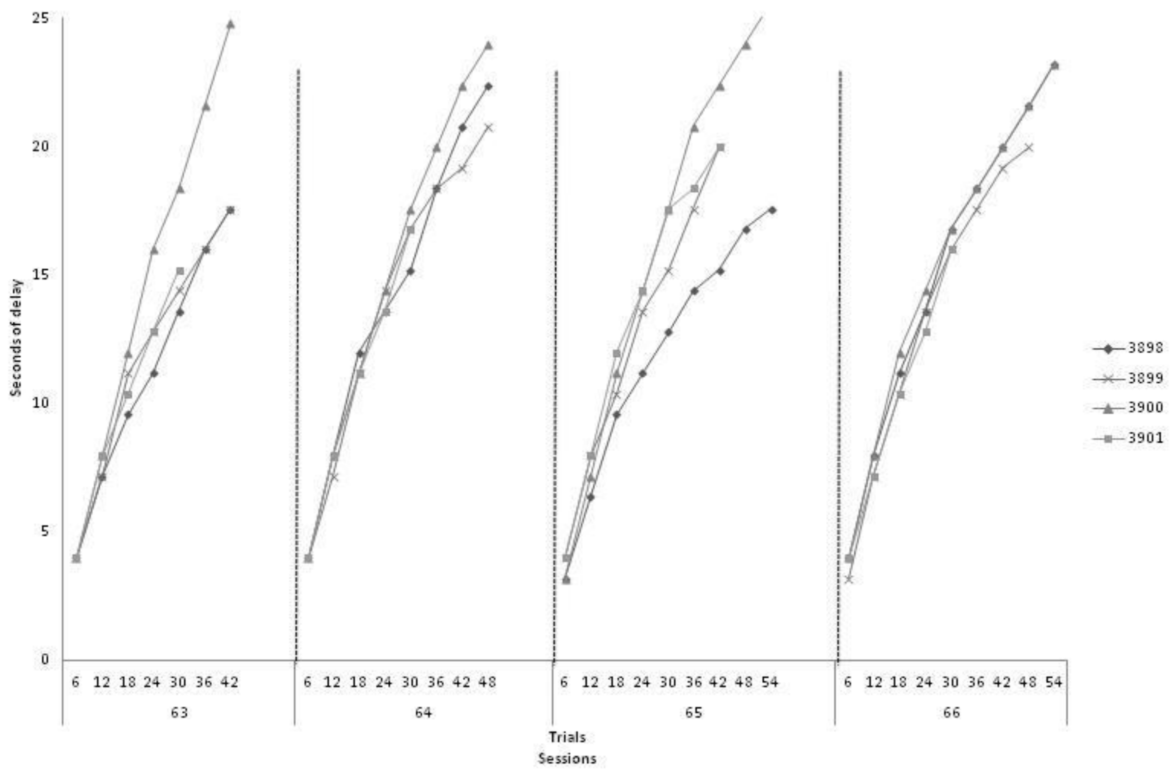

Figure 4.2. Delay contingenciencies linked to LL responses in the last trial of each block in sessions with Increasing Delay Condition 0.8s.

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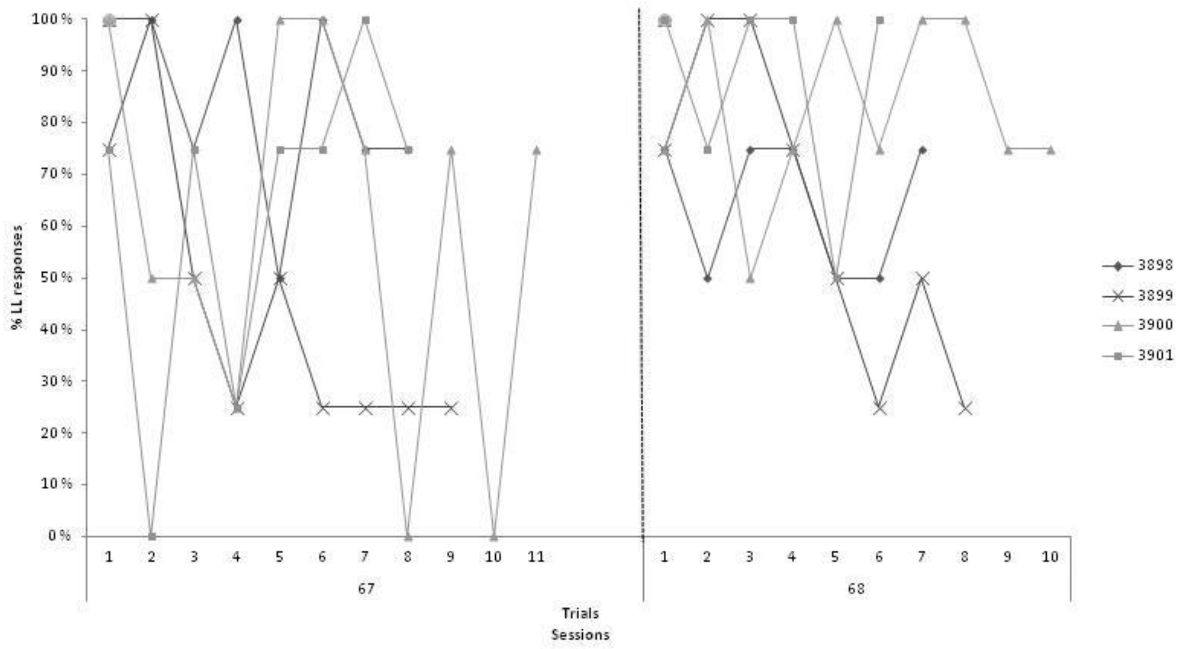

Figure 5.1. Percentage of LL responses in sessions with Decreasing Delay Condition 0.4s. Each data point represents the percentage of LL responses in one block four free-choice trials

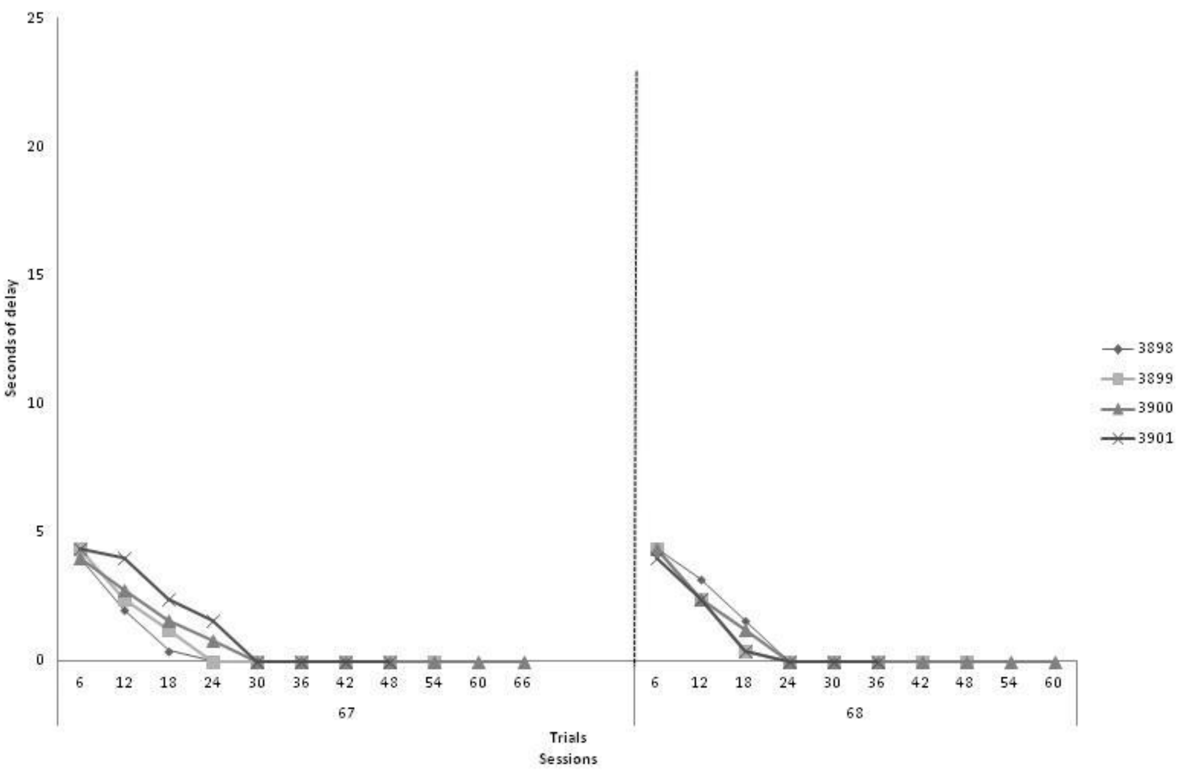

Figure 5.2. Delay contingenciencies linked to LL responses in the last trial of each block in sessions with Decreasing Delay Condition 0.4s.

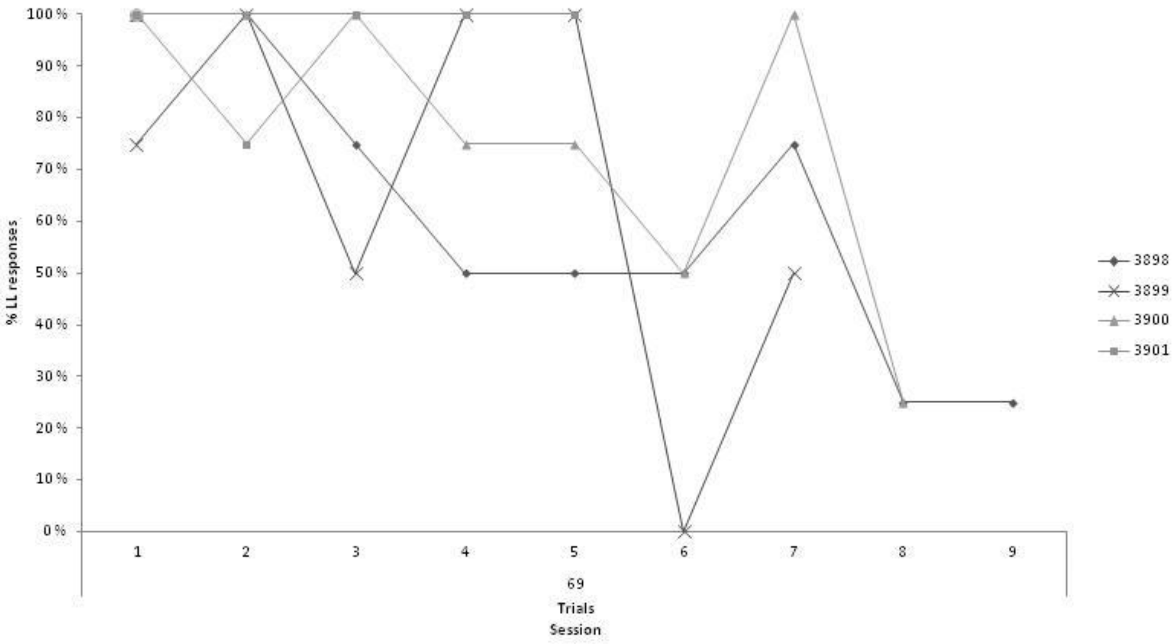

Figure 6.1. Percentage of LL responses in session with Decreasing Delay Condition 0.8s. Each data point represents the percentage of LL responses in one block four free-choice trials

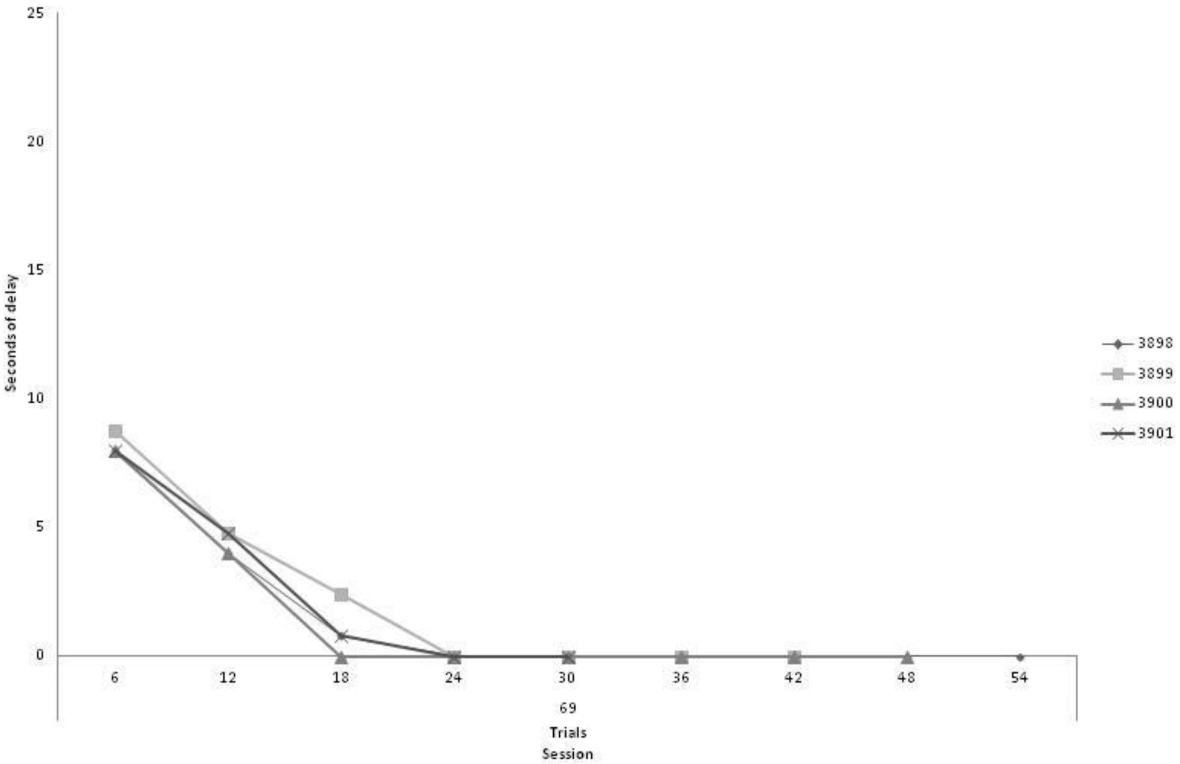

Figure 6.2. Delay contingenciencies linked to LL responses in the last trial of each block in sessions with Decreasing Delay Condition 0.8s.

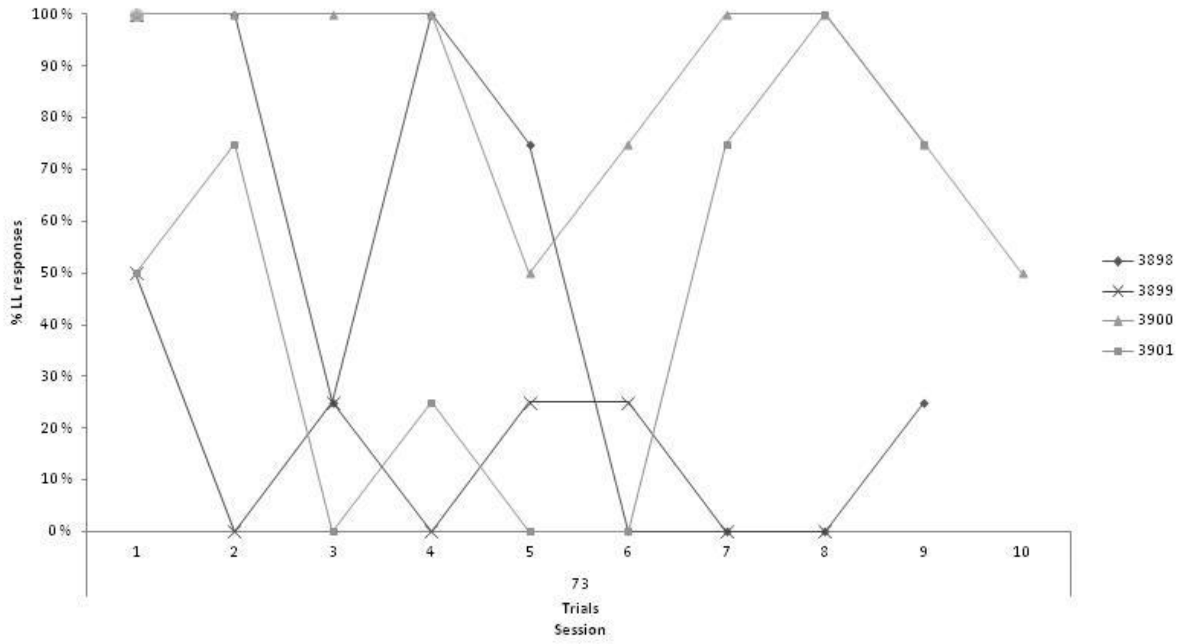

Figure 7.1. Percentage of LL responses in sessions with Decreasing Delay Condition 1s. Each data point represents the percentage of LL responses in one block four free-choice trials.

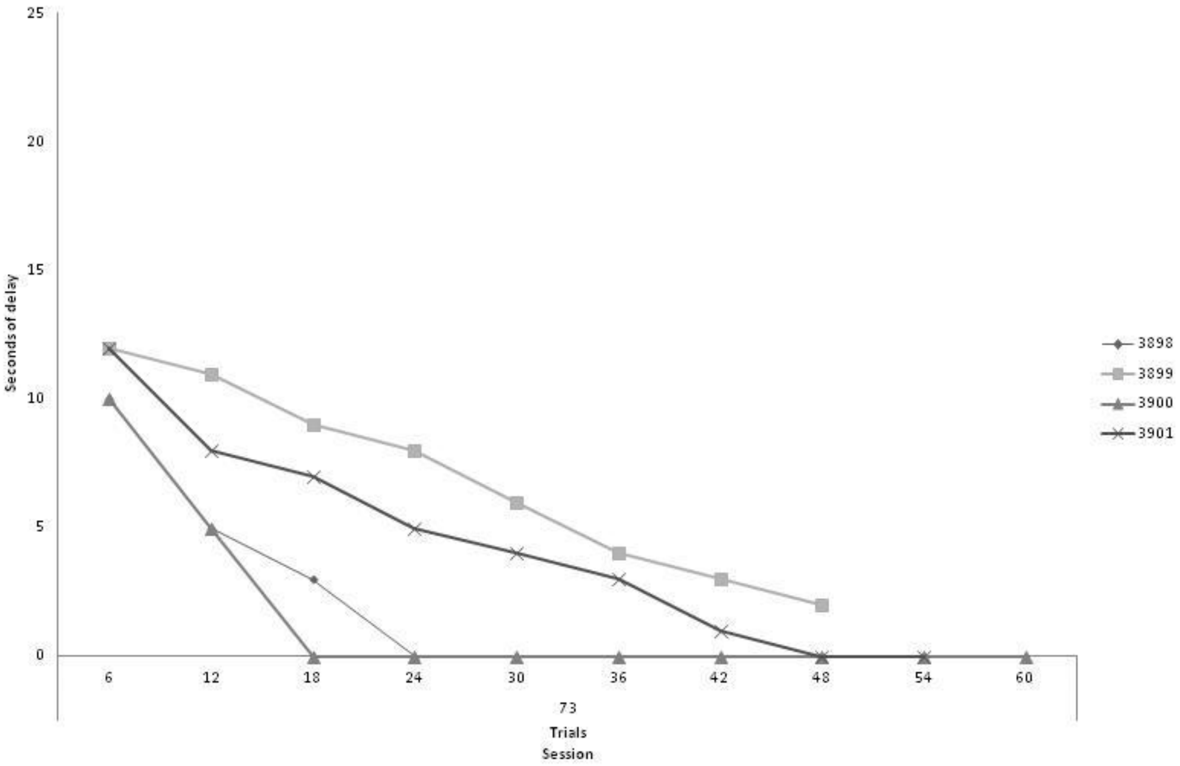

Figure 7.2. Delay contingenciencies linked to LL responses in the last trial of each block in sessions with Decreasing Delay Condition 1s.

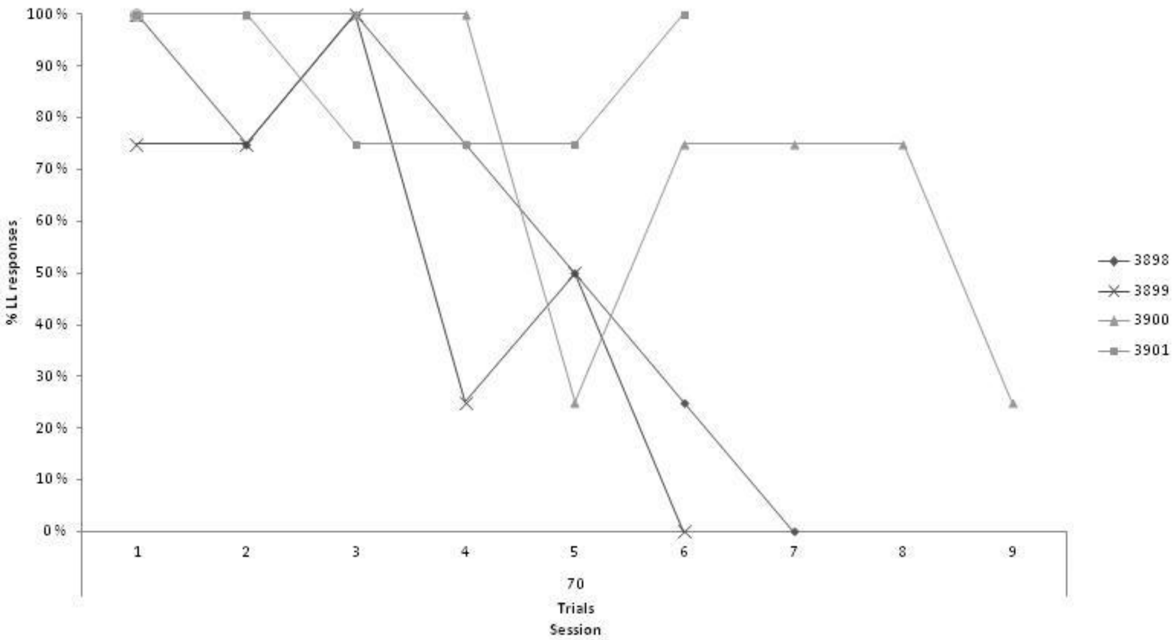

Figure 8. Percentage of LL responses in sessions with Constant Delay Condition 8s. Each data point represents the percentage of LL responses in one block four free-choice trials.

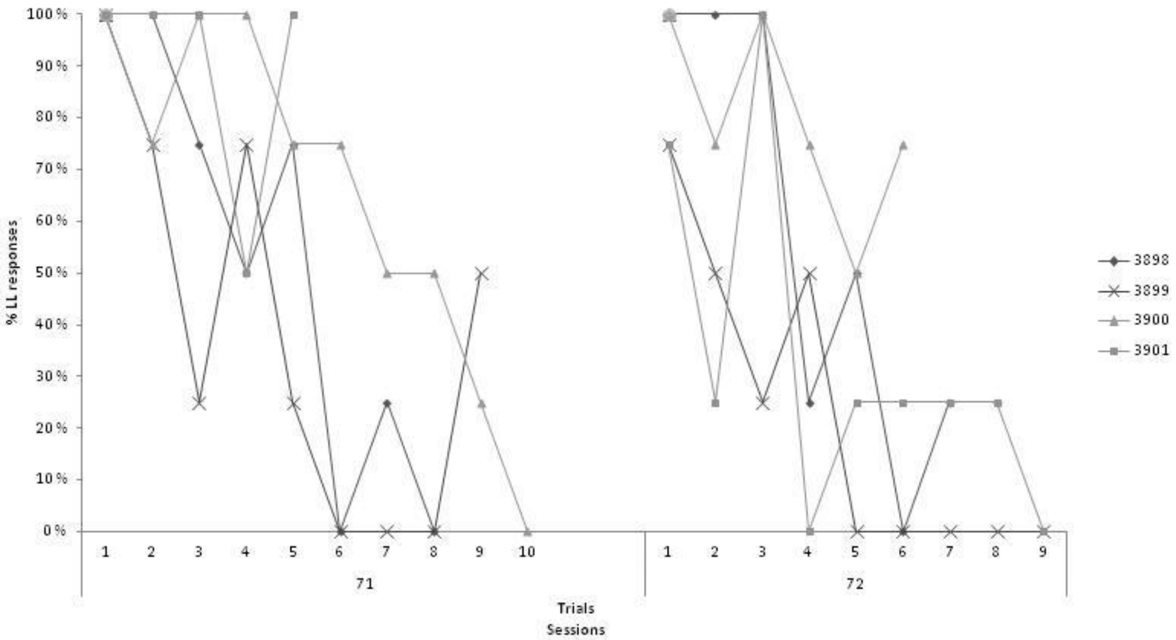

Figure 9. Percentage of LL responses in sessions with Constant Delay Condition 12s. Each data point represents the percentage of LL responses in one block four free-choice trials.

Table 1

Summary of procedural steps

Session	Condition	SR ratio	Settings	SR-schedule	Comments
1	Habituation				
2 – 5	Magazine training			CRF	
6 – 12	Magazine training			VT30	
13	Shaping			CRF	left lever
14	Shaping			CRF	right lever
15	Lever press			CRF	left lever
16	Lever press			CRF	right lever
17 – 20	Magazine training			CRF	new cages
21	Lever press			CRF	left lever
22	Lever press	x2		CRF	right lever
23	Preferense test	L1/R2		CRF	
24 – 25	Preference test	L1/R3		CRF	
26 – 32	Preference test	L1/R4		CRF	
33 – 44	Preference test	L4/R1		CRF	
45 -47	Preference test	L4/R1	ITI: 15s, FC 2/6	CRF	
48 – 62	Increasing Delay	L4/R1	ITI: 15s, FC 2/6, delay increase 0.4s	CRF	
63 – 66	Increasing Delay	L4/R1	ITI: 15s, FC 2/6, delay increase 0.8s	CRF	
67 – 68	Decreasing Delay	L4/R1	ITI: 15s, FC 2/6, delay decrease 0.4s	CRF	delay started at 6s
69	Decreasing Delay	L4/R1	ITI: 15s, FC 2/6, delay decrease 0.8s	CRF	delay started at 12s
70	Constant Delay	L4/R1	ITI: 15s, FC 2/6, delay 8s	CRF	
71 – 72	Constant Delay	L4/R1	ITI: 15s, FC 2/6, delay 12s	CRF	
73	Decreasing Delay	L4/R1	ITI: 20s, FC 2/6, delay decrease 1s	CRF	delay started at 15s

Note. ITI refers to intertrial interval. FC refers to ratio of forced choice/free choice. SR ratio refers to ratio of reinforcement size on left/right lever. SR schedule refers to reinforcement schedule.