Preference Reversals in Delay of Gratification

Jeremy M. Haynes
Utah State University

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PREFERENCE REVERSALS IN DELAY OF GRATIFICATION

by

Jeremy M. Haynes

A dissertation submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Psychology

Approved:

_____________________________
Gregory J. Madden, Ph.D.
Committee Member

_____________________________
Kerry Jordan, Ph.D.
Committee Member

_____________________________
Ryan Bosworth, Ph.D.
Committee Member

_____________________________
Julie K. Young, Ph.D.
Committee Member

_____________________________
Amy L. Odum, Ph.D.
Major Professor

_____________________________
D. Richard Cutler, Ph.D.
Vice Provost of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah
2022
ABSTRACT

PREFERENCE REVERSALS IN DELAY OF GRATIFICATION

by

Jeremy M. Haynes

Utah State University, 2022

Major Professor: Dr. Amy L. Odum
Department: Psychology

Intertemporal choices are decisions between outcomes occurring at different times. Patterns of intertemporal choices can be used to describe the degree of delay discounting, that is, the degree to which outcomes lose value as a function of their delay. Delay discounting has received widespread attention because steep delay discounting, characterized by a pattern of choices for smaller-sooner over larger-later outcomes, is associated with maladaptive behavior in people. In the present set of studies, I examine a facet of intertemporal choice that is related to delay discounting: preference reversals. Although there are multiple forms of preference reversal, I focus on those characterized by shifts in preference from a larger-later reward to a smaller-immediate reward after a choice of that larger-later reward. Little research has been dedicated to examining these preference reversals despite their potential role in some maladaptive behaviors (e.g., relapse). To address this gap, I first developed a procedure to examine these preference reversals in a preclinical rat model (Chapter II). After developing this procedure, I used it to examine the effect of delay pre-exposure training on preference reversals in rats, allowing me to investigate a potential process (i.e., changes in temporal expectations) contributing to these preference reversals (Chapter III). Importantly, identifying the
processes that contribute to these preference reversals may provide the means for developing interventions to avoid such reversals as they relate to human health.
Intertemporal choices are decisions between outcomes occurring at different times. For example, people may choose to quit smoking cigarettes for the delayed health-related benefits associated with abstention, or they may continue to smoke for the immediate gratification associated with smoking now. Importantly, patterns of intertemporal choices among people are associated with a number of maladaptive behaviors (e.g., cigarette smoking). In the present set of studies, I examine a facet of intertemporal choice: preference reversals. Although there are multiple forms of preference reversal, I focus on those characterized by shifts in preference from a larger-later reward to a smaller-immediate reward after a choice of that larger-later reward. Little research has been dedicated to examining these preference reversals despite their potential role in some maladaptive behaviors (e.g., relapse). To address this gap, I first developed a procedure to examine these preference reversals in a preclinical rat model (Chapter II). After developing this procedure, I used it to examine the effect of delay pre-exposure training on preference reversals in rats, allowing me to investigate a potential process (i.e., changes in temporal expectations) contributing to these preference reversals (Chapter III). Importantly, identifying the processes that contribute to these preference reversals may provide the means for developing interventions to avoid such reversals as they relate to human health. Thus, the goal of these studies was to provide an important step in progressing our understanding of preference reversals so that interventions can be developed to prevent them in people.
ACKNOWLEDGMENTS

I would first like to thank my advisor, Amy Odum, who taught me how to conduct research with the utmost scientific rigor while also teaching me how to be a kind and caring academic. I would also like to thank my former advisor, Josh Williams, who inspired my love for research and provided me the tools to pursue graduate school. While I am sad that this chapter of my life is coming to an end, I am thankful to have had both of you as advisors, and I am thankful to consider you both as my friends. Thank you to my dissertation committee, Greg Madden, Julie Young, Kerry Jordan, and Ryan Bosworth for your support and guidance on my dissertation. I am honored to have you all on my committee. In addition, I am thankful for my lab mates, both past (Casey Frye & Annie Galizio) and present (D. Perez, Mariah Willis-Moore, & Devanio Cousins), who all helped me get this far. Finally, I would like to thank my parents, Susan and Clay, as well as my brother Sam, who loved and supported me throughout my time at USU. I could not have done it without you all, thank you.

Jeremy Haynes
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CHAPTER I

INTRODUCTION

Intertemporal choices refer to decisions between outcomes occurring at different times (Madden & Johnson, 2010). These decisions may be as trivial as deciding to eat lunch before or after teaching a class, or as important as deciding to enter the workforce now or to attend graduate school for a PhD later. People likely encounter such decisions frequently in their everyday life; however, in the laboratory, intertemporal choice is often studied using tasks that present participants with a series of choices between a smaller-sooner monetary reward and a larger-later monetary reward (e.g., $500 now vs. $1000 in 1 year; Bickel et al., 1999). Intertemporal choice tasks have also been developed for non-human animals. For example, a task for rats may involve presenting a series of choices between a smaller-sooner food reward and a larger-later food reward (e.g., 1 food pellet immediately vs. 3 food pellets after 20 seconds; Evenden & Ryan, 1996). Patterns of preference on intertemporal choice tasks can be used to characterize delay discounting, the degree to which an outcome loses value as a function of its delay (Mazur, 1987; Odum, 2011). Steep discounting is characterized by preference for a smaller-sooner reward over a larger-later reward across a range of delays to the larger reward, indicating that the value of the larger reward decreases precipitously as the delay to its receipt increases. Shallow discounting is characterized by the opposite pattern of preference and indicates that the value of the larger reward decreases slowly as the delay to its receipt increases.
Importantly, the degree of delay discounting is predictive of many socially significant behaviors among people. For example, steep discounting is correlated with alcohol misuse (Field et al., 2007; Vuchinich & Simpson, 1998), problematic gambling (Cosenza et al., 2017; Ledgerwood et al., 2009), and risky sexual behavior (Lawyer & Mahoney, 2018). Steep delay discounting is also observed among people who use tobacco- and e-cigarettes (DeHart et al., 2020; Friedel et al., 2014; Mitchell, 1999), heroin (Madden et al., 1997), cocaine (Coffey et al., 2003), and methamphetamine (Ballard et al., 2015; Hoffman et al., 2006; for meta-analyses, see Amlung et al., 2017 & MacKillop et al., 2011). Several researchers suggest that steep discounting could serve as an important target for reducing such maladaptive behaviors in people (e.g., Bickel et al., 2012); however, it is important to recognize that the causal relation between steep discounting and these maladaptive behaviors has yet to be established (Rung & Madden, 2018). Further basic understanding of intertemporal choice may be necessary to fully describe the potential cause-and-effect relation between patterns of decision-making characterized by steep discounting and these maladaptive behaviors (Bailey et al., 2021).

In the present set of studies, I explore a facet of intertemporal choice that is characterized by shifts in preference from a larger-later reward to a smaller-sooner reward (i.e., preference reversals). For example, when an individual who smokes cigarettes decides to quit smoking for better health in the future (e.g., improved lung function; American Lung Association, 2020), they often have the opportunity to reverse their preference in favor of smoking again. Preference reversals can take multiple forms. Preference reversals with cigarette smoking are also likely influenced by the physiological aspects of nicotine addiction. Preference reversals likely also likely occur for non-physiological outcomes such as monetary outcomes (e.g., preference shifting from saving for retirement to purchasing commodities now).

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1 Preference reversals with cigarette smoking are also likely influenced by the physiological aspects of nicotine addiction. Preference reversals likely also likely occur for non-physiological outcomes such as monetary outcomes (e.g., preference shifting from saving for retirement to purchasing commodities now).
One form of preference reversal occurs when preference shifts from a larger-later reward to a smaller-sooner reward as a function of both rewards becoming temporally proximal. For example, a person may set a quit date to stop smoking for the health-benefits associated with abstention; however, upon reaching that quit date, the person may reverse their preference in favor of continuing to smoke. Such preference reversals are predicted by the hyperbolic discounting model and have been investigated in a number of studies with both humans and non-human animals (Ainslie & Herrnstein, 1981; Green & Estle, 2003; Green et al., 1994; Pope et al., 2016; Rachlin & Green, 1972; Yi et al., 2016; Yi et al., 2020).

Another form of preference reversal exists, however, in which preference shifts from a larger-later reward to a smaller-immediate reward after the larger-later reward is chosen. For example, a person may successfully stop smoking on their quit date; however, they may encounter multiple occasions to smoke again after having quit (e.g., by passing ‘smoke’ shops while driving). This form of preference reversal has received much less attention despite being theoretically interesting because it is not predicted by hyperbolic discounting but has been shown formally in the laboratory with children (Forzano et al., 2011) and with rats (Reynolds et al., 2002). Although I discuss both forms of preference reversal in the studies described below, I focus on this latter form because there is a lack of basic understanding as to why this preference reversal occurs. Because it is unclear as to why these preference reversals occur, it is also unclear as to what interventions could reduce them. Furthermore, this lack of understanding could be problematic because many interventions have been developed to increase choices for larger-later outcomes (i.e., to reduce steep discounting; Rung & Madden, 2018) but these
interventions may be less helpful if people later reverse their preference from these outcomes (Reyes-Huerta et al., 2018). For example, increasing the likelihood that someone chooses to quit smoking may not translate to long-term abstinence. Thus, I developed a procedure to study these preference reversals and then I used this procedure to examine a potential process that may contribute to them.

In Chapter II, I describe a study in which I developed and tested a procedure that would allow me to measure preference reversals in rats (Haynes & Odum, 2022). I chose to develop this procedure in rats because non-human animal models, particularly rodent models, provide a high degree of experimental control that allow us to answer theoretically important questions that could also be important for developing interventions to improve human health (Kalenscher & van Wingerden, 2011; Venniro et al., 2020). To develop this procedure, I modified a task initially introduced by Reynolds et al. (2002) that was used to show that rats will ‘defect’ (i.e., reverse their preference) on their choices of a larger-later reinforcer in an adjusting-amount delay of gratification task. After developing this procedure (an increasing-delay delay of gratification task; Evenden & Ryan, 1996), I tested rats on that procedure across two experiments.

From the experiments in Chapter II, I was able to evaluate whether my data were consistent with predictions from two theoretical models of preference reversals in delay of gratification: Reynolds and Schiffbauer’s (2005) Feedback Model of Delay-Related Impulsive Behavior and McGuire and Kable’s (2013) Normative Perspective (see also Rachlin, 2000). The results of Experiment 1 (Chapter II-1) were consistent with the Feedback Model; however, the results from Experiment 2 (Chapter II-2) were inconsistent with that model. In contrast, the results from both experiments were
consistent with the Normative Perspective. Based on these findings, I conducted two follow-up experiments in Chapter III to explore predictions based on the perspectives from McGuire and Kable and Rachlin regarding why these preference reversals occur.

In Chapter III, I examined whether temporal learning plays a role in preference reversals based on predictions from McGuire and Kable (2013) and Rachlin (2000). According to their perspectives, preference reversals can occur when the expected delay to a larger-later reward changes while an individual is waiting for that reward. If the expected (i.e., estimated) delay to a larger-later reward increases beyond that of the original expected delay, the discounted value of that reward may fall below that of the smaller-immediate reward and thus we would expect a preference reversal to occur. In addition, McGuire and Kable’s Normative Perspective predicts that ‘temporal expectations’ are developed based on one’s prior experience with the delayed outcome. We tested the predictions described above by using delay pre-exposure procedures as a potential method of influencing temporal expectations that could also influence preference reversals in rats (e.g., Renda et al., 2016; Smith et al., 2015). The results of these experiments allowed us to determine the role of temporal learning in delay of gratification which is of theoretical significance in identifying why these reversals occur, and of clinical significance for developing interventions to reduce these reversals as they relate to human health (e.g., as in relapse; Reyes-Huerta et al., 2018). Thus, the present set of studies provide an important step in progressing towards a better understanding of preference reversals as a facet of intertemporal choice.
References

https://doi.org/10.3758/BF03209777


https://doi.org/10.1016/j.pharmthera.2012.02.004


CHAPTER II

TESTING DELAY OF GRATIFICATION IN RATS USING A WITHIN-SESSION INCREASING-DELAY TASK

Abstract

In delay discounting, preference reversals refer to shifts in preference from a larger-later reward to a smaller-sooner reward. Steep hyperbolic discounting predicts a preference reversal when a smaller-sooner and larger-later reward both become temporally proximal; prior research is consistent with this prediction. Hyperbolic discounting does not predict a preference reversal, however, after an individual chooses a larger-later reward over a smaller-immediate reward; prior research is inconsistent with this prediction. We sought to replicate and extend these findings using a delay of gratification task in rats. The task included a defection response which allowed rats to reverse their preference after choosing a larger-later sucrose reinforcer to instead obtain a smaller-immediate sucrose reinforcer. In Experiment 1, we found that rats would defect on their choice of the larger-later reinforcer, systematically replicating prior research. We also found that experience on the delay of gratification task led to decreases in defection responses. In Experiment 2, we found that prior experience on an intertemporal choice task, with no opportunity to defect, also led to few defection responses on the delay of gratification task. We discuss our findings in the context of whether inhibitory control or temporal learning could be involved in delay of gratification.

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Keywords: delay discounting, delay of gratification, preference reversals, generalized linear mixed modeling, rat

Introduction

Preference for a delayed outcome is often described in terms of delay discounting, the process by which an outcome loses value as a function of the delay to its receipt (Mazur, 1987; Odum, 2011). The rapid loss in value of a delayed outcome (i.e., steep delay discounting) is associated with a number of maladaptive behaviors in people including texting while driving (Hayashi et al., 2016), problematic gambling (Cosenza et al., 2017; Ledgerwood et al., 2009), alcohol misuse (Field et al., 2007; Vuchinich & Simpson, 1998), cigarette smoking (Friedel et al., 2014; Mitchel, 1999), and the use of illicit drugs, such as heroin (Madden et al., 1997), cocaine (Coffey et al., 2003), and methamphetamine (Ballard et al., 2015; Hoffman et al., 2006; for a review see MacKillop et al., 2011). Furthermore, studies with preclinical rat models show that steep delay discounting predicts the acquisition and escalation of cocaine self-administration (Anker et al., 2009; Perry et al., 2005) and relapse of nicotine self-administration (Diergaarde et al., 2008). Thus, the study of delay discounting is important for further understanding the processes involved in a number of maladaptive behaviors.

The degree of delay discounting can be measured with intertemporal choice tasks that assess preference between a smaller-sooner reward and a larger-later reward. For example, an intertemporal choice task for humans may involve asking participants their preference between $500 now or $1000 in 1 year (e.g., Bickel et al., 1999); an intertemporal choice task for non-humans (e.g., rats) may involve assessing preference between 1 food pellet immediately or 3 food pellets after 20 s (e.g., Evenden & Ryan,
Steep delay discounting is characterized by a pattern of preference for the smaller-sooner reward over the larger-later reward across a series of delays to the larger-later reward. For multiple species (e.g., humans, rats, monkeys, and pigeons), the form of the discounting curve follows a hyperbolic or hyperbolic-like function, characterized by steep decreases in value at shorter delays and shallower decreases in value at longer delays (Green et al., 2007; Huskinson et al., 2015; Madden et al., 1999; Madden et al., 2003; Mazur & Biondi, 2009). The hyperbolic discounting function is given by

\[ V = \frac{A}{1 + k \times D} \]  

Equation 1

in which \( V \) is the discounted value of the delayed outcome, \( A \) is the amount of the delayed outcome, \( k \) is a free parameter describing the degree of discounting, and \( D \) is the delay to that outcome (Mazur, 1987).

An important prediction of hyperbolic discounting is the change in preference between a smaller-sooner reward and a larger-later reward as a function of when an individual chooses between those rewards (Green et al., 1994). To illustrate, Figure 1A shows hypothetical data illustrating steep delay discounting according to the hyperbolic discounting model (Equation 1). The figure displays the value of a smaller-sooner reward and a larger-later reward as a function of time. When the smaller-sooner and larger-later rewards are temporally distant (Time 1), the value of the larger-later reward is higher than the value of the smaller-sooner reward. However, when the smaller-sooner and larger-later rewards are temporally proximal (Time 2), the value of the smaller-sooner reward is higher than that of the larger-later reward. Therefore, hyperbolic discounting predicts that preference will shift from the larger-later reward when the outcomes are temporally distant (Time 1), to the smaller-sooner reward when the outcomes are
temporally proximal (Time 2). Such preference reversals have been demonstrated in human and non-human animals, providing evidence in favor of the hyperbolic discounting model (Green & Estle, 2003; Green et al., 1994; Rachlin & Green, 1972).

Figure 1
Preference Reversals According to Hyperbolic Discounting

Note. Hypothetical data showing the value of a smaller-sooner reward and a larger-later reward as a function of time according to hyperbolic discounting (Equation 1). Black bars represent the value of the reward when it is immediately available. Top panel (A): Value with steep delay discounting. Bottom panel (B): Value with shallow delay discounting. The immediate availability of the smaller-sooner reward during the delay to the larger-later reward is depicted as multiple black bars between Time 2 and Time 3. See text for details.

The study of preference reversals is important because preference reversals may contribute to maladaptive behaviors such as relapse (Reyes-Huerta et al., 2018). For example, when an individual is in treatment for alcohol abuse, access to alcohol (the
smaller-sooner reward) and future social- and health-related benefits of alcohol-abstinence (the larger-later reward) are both temporally distant; therefore, the individual likely prefers the future benefits associated with abstinence. However, when the individual leaves treatment later, and they are confronted with the choice between using or abstaining from alcohol, the individual may show a preference reversal. That is, preference shifts from the future benefits of alcohol-abstinence in favor of drinking alcohol now. Thus, the study of preference reversals is important for developing strategies that could increase choice of larger-later rewards with the goal of translating these strategies into methods of promoting human health.

According to hyperbolic discounting, strategies that reduce the degree of discounting should prevent preference reversals. To illustrate, Figure 1B shows the same outcomes as Figure 1A, but with more shallow discounting. In this figure, the value of the larger-later reward remains above that of the smaller-sooner reward even when the outcomes become temporally proximal (Time 2); therefore, we would not predict a preference reversal. Research with human participants supports this prediction, as individuals who show more shallow discounting are also less likely to reverse their preference from a delayed outcome (Pope et al., 2019; Yi et al., 2016). Thus, interventions that reduce the degree of discounting could be useful in preventing preference reversals.

For these interventions to succeed, however, preference for the larger-later reward must be maintained after choosing it. That is, if the smaller-sooner reward is immediately available during the delay to the larger-later reward, a preference reversal could still occur. In these situations, however, hyperbolic discounting predicts that preference for
the larger-later reward will be maintained after choosing it. Specifically, the value of the smaller-immediate reward should remain constant throughout the delay because it is immediately available (see Figure 1B, Time 2 to Time 3). During the same time, however, the value of the larger-later reward should increase as the delay to its receipt decreases. Thus, assuming that the value of the smaller-immediate reward is constant, we would expect preference for the larger-later reward to remain higher after it is chosen (i.e., during the delay to its delivery).

Although hyperbolic discounting predicts that individuals will maintain their preference for a larger-later reward after choosing it, most laboratory intertemporal choice tasks cannot be used to test this prediction. Specifically, most intertemporal choice tasks do not have a response option that allows a preference reversal to occur after a choice of the larger-later reward (e.g., Bickel et al., 1999; Evenden & Ryan, 1996). To fill this methodological gap, Reynolds et al. (2002) developed the adjusting-amount ‘delay of gratification’ task for rats. In their task, a rat could choose between a smaller-immediate, adjusting amount of water and a larger-later fixed (250 µL) amount of water. If the rat chose the larger option, the rat could make a ‘defection response’ during the delay which resulted in the immediate delivery of the smaller reinforcer and the cancellation of the delivery of the larger reinforcer. Using the adjusting-amount delay of gratification task, Reynolds et al. found that rats would ‘defect’ on their choice of the larger option (i.e., reverse their preference; for similar findings in children, see Forzano et al., 2011). Because this finding is inconsistent with predictions from hyperbolic discounting, Reynolds et al. suggested that defection responses in the delay of gratification task may represent failures in inhibitory control, a process separate from delay discounting (e.g.,
Broos et al., 2012). That is, the initial choice of a larger-later reward may reflect delay
discounting, but whether preference for that reward is maintained during the delay may
reflect inhibitory control.

Alternatively, however, McGuire and Kable (2012, 2013; see also Rachlin, 2000)
have suggested that defection responses (i.e., preference reversals) could reflect decisions
based on the discounted value of an outcome as a function of its estimated delay, what
they refer to as the ‘Normative Perspective’. According to the Normative Perspective,
when an individual chooses a larger-later reward, that individual may defect on that
choice if the estimated delay to that reward changes. Specifically, if the estimated delay
exceeds the original delay, the discounted value of the larger-later reward may fall below
that of the smaller-immediate reward and thus, we would expect preference to shift in
favor of the smaller-immediate reward. In the present set of experiments, we developed a
procedure that could be used to test predictions, such as those based on the Normative
Perspective, regarding the conditions under which these preference reversals occur.

The purpose of the present set of experiments was to systematically replicate and
extend the experiment by Reynolds et al. (2002), who found that rats defected on their
initial choice of a larger-later reinforcer in favor a smaller-immediate reinforcer.³

Systematic replication is important to evaluate reproducibility (Open Science

³ These data were collected between 2018 and 2020 from rats that completed an increasing-delay DoG task
(described in Experiment 1) as well as an increasing-delay intertemporal choice (ITC) task (described in
Experiment 2) using a crossover design. That is, rats in Experiment 1 completed DoG then ITC, and rats in
Experiment 2 completed ITC then DoG. We found strong, unexpected order effects (those reported in
Experiment 2) that rendered the original intention to examine correlations between performance across the
two tasks untenable. Therefore, although the experiments were conducted concurrently across two cohorts,
we present these data separately and focus on the effects of experience on DoG performance. Supplemental
files which include data in both raw and summarized forms from both tasks as well as a further discussion
of those data are available for interested readers on the Open Science Framework
(https://osf.io/wup57/?view_only=67ba6fc6bb114fb3b835c9e38621d93c).
Collaboration, 2015) and build our science on solid findings. To do this, we first modified the adjusting-amount delay of gratification task developed by Reynolds et al. We used the same delay-progression as the adjusting-amount task but manipulated the delays within-session rather than between-session (cf. Evenden & Ryan, 1996). Delays were presented in an increasing progression, and rats could defect on a choice of the larger-later reinforcer during the delay to receiving that reinforcer. Within-session increasing-delay tasks are useful in studying the effects of acute manipulations on intertemporal choice (e.g., drug administration; Evenden & Ryan, 1996); therefore, extending Reynolds et al.’s adjusting-amount task to a within-session increasing-delay task could also provide the methodology for studying this form of preference reversal under acute manipulations. Finally, to make the procedure more practical, we used a 20% sucrose solution instead of water as the smaller-immediate and larger-later reinforcers, thus allowing the use of food deprivation rather than water deprivation. Further, the amount of the smaller-immediate reinforcer was held constant, instead of adjusting across trials. The delay of gratification (DoG) task was similar to other within-session increasing-delay tasks, but rats had the opportunity to reverse their preference; therefore, we will hereafter refer to the task as an increasing-delay DoG task.

**Experiment 1**

The goal of Experiment 1 was to provide a systematic replication of Reynolds et al.’s (2002) experiment using a within-session increasing-delay DoG task. Rats completed the increasing-delay DoG task, and across sessions we examined the frequency with which rats chose and subsequently waited for a larger-later sucrose reinforcer when a defection response was available during the delay to that reinforcer.
Method

Subjects

A total of 13 experimentally naïve male Wistar rats were used across the two experiments, with 7 randomly assigned to Experiment 1. Rats were obtained from Charles River Laboratories, aged approximately 60 days upon arrival. Rats were housed individually in a temperature-controlled colony with a 12:12 hour light/dark cycle (lights on at 700 hours) and experimental sessions were conducted daily during the light cycle. The colony was located within a facility that was certified by the American Association for Laboratory Animal Care (AALAC). Rats were maintained at 85% of their free-feeding weights by supplemental post-session rat chow. Free-feeding weights were based on growth curves provided by Charles River Laboratories. All procedures were approved prior to the beginning of the experiment by the university’s Institutional Animal Care and Use Committee (IACUC Protocol 2532).

Apparatus and Materials

Two Med Associates® operant conditioning chambers in sound-attenuating shells were used. Both chambers measured 29 cm by 24 cm by 20 cm. One wall of each chamber had a noseport equipped with a light and a head entry detector. The opposite wall of each chamber had a houselight and three equidistant retractable levers. Above the two side levers (left and right) were circular stimulus lights. Below the side levers were Coulbourn Instruments liquid reservoirs, connected to BD 60 mL syringes (Becton, Dickinson and Company©) via 0.8 mm (internal diameter) Tygon® tubing. The syringes delivered a 20% sucrose solution using two Med Associates© single-speed syringe pumps housed outside of the chamber. The 20% sucrose solution was made from granulated
sugar mixed with distilled water every 2 – 3 days. Programming and data collection were conducted through Medstate notation.

**Procedure**

*Initial Training*

We used autoshaping to train rats to press the side levers (Brown & Jenkins, 1968; Papini & Brewer, 1994). Autoshaping sessions were composed of 30 trials, beginning every 90 s on average (Papini & Brewer, 1994). At the beginning of each trial, the left or right lever, randomly determined, extended into the chamber and the stimulus light above the lever illuminated. During autoshaping and throughout lever training, each lever (left or right) was randomly presented an equal number of times according to a two-item list (left and right lever) drawn from without replacement. After the lever was presented and either 10 s elapsed or the rat pressed the lever, the lever retracted, the lever light extinguished, and 100 μL of sucrose solution was delivered. Rats completed four sessions of autoshaping.

After autoshaping, rats were transitioned to fixed-ratio (FR) 1 lever-press training. Fixed-ratio 1 lever-press training sessions were composed of 60 trials. At the start of a trial, the houselight illuminated and one of the side levers, randomly determined from a 10-item list (5 of each side), extended into the chamber and the stimulus light above the lever illuminated. After a rat pressed the lever, the houselight and lever light extinguished, the lever retracted, and 100 μL of sucrose solution was delivered. If the rat did not press the lever within 10 s, it was counted as an omission and the houselight and lever light extinguished, the lever retracted, and the trial ended without sucrose. After each trial, there was a compensating intertrial interval (ITI) that maintained 60 s between
the start of each trial. This compensating ITI was also used throughout all subsequent conditions (e.g., amount-discrimination training). Rats completed two sessions of FR1 lever-press training.

After FR1 lever-press training, rats completed two (or more) sessions of chained FR1 nose-poke FR1 lever-press training, also composed of 60 trials. At the start of a trial, the houselight and noseport light illuminated. After the rat made a nose-poke, the noseport light extinguished and one of the side levers, randomly determined from a 10-item list, extended into the chamber and the stimulus light above the lever illuminated. After the lever was presented, a single lever-press resulted in 100 μL of sucrose solution. If the rat did not make a nose-poke within 10 s of trial onset or did not press a lever within 10 s after lever extension, the trial ended and was counted as an omission. A rat was transitioned to amount-discrimination training after obtaining at least 90% of the available sucrose deliveries from two consecutive sessions of chained FR1 nose-poke FR1 lever-press training.

**Amount-Discrimination Training**

The goal of amount-discrimination training was to establish discrimination between a smaller (50 μL) and larger (150 μL) amount of sucrose solution. Sessions ended after 60 trials or 65 min, whichever occurred first. The 60-trial sessions were divided into five blocks of 12 trials each. Blocks began with two forced-choice trials to expose rats to each outcome. At the start of a forced-choice trial, the houselight and noseport light illuminated. After a rat made a nose-poke into the port (i.e., a centering response), the port light extinguished, the middle lever extended, and one of the side levers, randomly determined, extended. The middle lever was not associated with any
programmed consequences and served as an inactive lever. After the rat pressed the extended side lever, both levers retracted, the houselight and lever light extinguished, sucrrose solution was delivered, and the trial ended. During one forced-choice trial, a press on one side lever resulted in 50 μL of sucrrose solution immediately and during the other forced-choice trial, a press on the other side lever resulted in 150 μL of sucrrose solution immediately. The lever-outcome arrangement was counterbalanced across rats; however, that arrangement remained constant within and across sessions for each rat. That is, for some rats, the left lever was always associated with 50 μL of sucrrose solution and the right lever was always associated with 150 μL of sucrrose solution; for the other rats, the reverse was true.

After two forced-choice trials, there were 10 free-choice trials. Free-choice trials were structured the same as forced-choice trials; however, both side levers and the middle lever were extended after the rat made a centering response. If a rat did not make a centering response or a side-lever choice response within 10 s of trial onset or lever extension, respectively, the trial ended and was counted as an omission (i.e., there was a 10-s limited hold). The 10-s limited hold was in place for both forced- and free-choice trials; however, if a rat omitted a forced-choice trial, that trial was repeated until the rat responded, or the session ended after 65 min. This session structure was used during amount-discrimination training as well as during the increasing-delay DoG task (see below).

During amount-discrimination training, we conducted lever reversals to identify and address potential lever biases. Specifically, a rat was exposed to the same lever-

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4 Inactive responses were relatively rare across all phases of the experiment and not reported here. These data are available on OSF.
outcome arrangement until the larger (150-μL) option was chosen on at least 80% of trials for two consecutive sessions. After a rat met the 80% choice criterion, the lever-outcome arrangement was reversed until the rat met the 80% choice criterion on the new arrangement. Each rat was exposed to four lever reversals. We implemented remedial training for one rat (DG4) that did not meet the 80% choice criterion in four sessions and showed no increasing trend in choice of the 150-μL option. Remedial training involved at least two consecutive sessions of all forced-choice trials for the 150-μL option (Renda et al., 2018). After remedial training, DG4 was returned to amount-discrimination and required no further remedial training. After amount-discrimination training, rats began the increasing-delay DoG task (described next).

**Increasing-Delay Delay of Gratification (DoG) Task**

During the increasing-delay DoG task, the delay to the larger (150-μL) reinforcer increased across blocks of trials in the following progression: 0, 4, 8, 16, and 32 s (Evenden & Ryan, 1996; Reynolds et al., 2002). If a rat selected the 150-μL option, that lever retracted, leaving the inactive lever and the lever for the smaller-immediate (50-μL) option available (see Figure 2, top panel). If the rat responded on the lever for the 50-μL option during the delay (i.e., made a defection response), all remaining levers retracted, 50 μL of sucrose solution was delivered immediately, and the trial ended. If the rat waited the full delay to the larger reinforcer (i.e., did not respond on the lever for the 50-μL option), all remaining levers retracted and 150 μL of sucrose solution was delivered. During the delay to the 150-μL reinforcer, the stimulus light above that lever flashed on/off every 0.5 s. If a rat chose the 150-μL option on less than 80% of the trials in the 0-s delay-block for three consecutive sessions with no increasing trend across those
sessions (i.e., failed to discriminate amount), that rat was returned to amount-discrimination training until choice of the 150-μL option was at least 80% of trials for two consecutive sessions. One rat (DG1) required additional amount-discrimination training because it failed to discriminate amount at the beginning of the increasing-delay DoG task. After further amount-discrimination training, this rat was returned to the increasing-delay DoG task and did not require any further training. Sessions prior to the return to amount-discrimination training were not included in the analysis (see below).

**Figure 2**
*Arrangement of Operant Chamber When Larger-Later Sucrose Reinforcer Chosen*

*Note.* Arrangement of operant chamber after a rat pressed the lever for the larger-later (150-μL) option during the increasing-delay DoG task (top panel, Exp 1 and 2) and during the increasing-delay ITC task (bottom panel, Exp 2). Levers filled white represent extended levers and levers filled black and shortened represent retracted levers.
Rats finished the increasing-delay DoG task based on behavioral stability and a fixed-time criterion (Perone, 1991). Behavioral stability was assessed according to the proportion of initial choices for the larger-later (150-μL) option (referred to as initial choice proportion) and the proportion of choices in which the larger-later option was obtained without defecting (referred to as final choice proportion). For example, if a rat initially chose the 150-μL option on 5 out of 10 trials within a particular delay-block but defected on two of those choices, initial choice proportion within that block would be .50 whereas final choice proportion would be .30. Rats completed a minimum of 30 sessions and behavior was considered stable if, for each block, the average initial choice proportion and final choice proportion from the last three sessions and the previous three sessions did not differ from the respective combined six-session average by more than 10%. Conditions were terminated after behavioral stability or 60 daily sessions, whichever occurred first.

**Data Analysis**

For each rat, we organized choice data from each trial in terms of initial choices and final choices for the larger-later (150-μL) option (cf. Forzano et al., 2011). We defined an initial choice in terms of the outcome that a rat initially chose at the start of a trial, regardless of whether the rat made a defection response. We defined a final choice in terms of the outcome that a rat ultimately received, depending on whether the rat made a defection response. For example, if a rat initially chose the 150-μL option but defected on that choice, that trial would be coded as an initial choice for the 150-μL option and as a final choice for the 50-μL option. We only included sessions in which a rat chose the 150-μL option on at least 80% of trials in the 0-s delay-block (i.e., showed discrimination
between 50 μL and 150 μL of sucrose solution). In addition, we removed data from occasional sessions with temporary equipment failures (e.g., computer crash) or experimenter-produced errors (e.g., accidental feeding prior to the session). Sessions included in the analyses were treated as consecutive sessions. Finally, we excluded two sessions from one rat (DG1) that completed fewer than 10 trials within those sessions. We observed longitudinal changes in the degree to which initial choices differed from final choices; therefore, we used mixed effects modeling to capture these longitudinal changes.

To analyze initial and final choice data, we used a generalized linear mixed model (GLMM) with a logit link because our data were binary (50-μL or 150-μL option). A GLMM with a logit link is a logistic regression model appropriate for analyzing repeated measures and is well-suited for handling missing data (i.e., omissions) and unbalanced datasets (i.e., unequal number of sessions; for a more thorough discussion of using GLMMs for analyzing choice data see Young, 2018; Hox et al., 2017). We first fit a random intercept model using choice (0 = 50-μL option; 1 = 150-μL option) as the dependent variable and delay, choice type (initial vs. final), session, and their two- and three-way interactions as predictors (i.e., a full factorial). Delay and session were treated as continuous predictors. We log-transformed the delays because this improved model fit according to Akaike Information Criteria (Burnham & Anderson, 2004; Young et al., 2012; Young, 2018). We added a constant of 1 to each delay to avoid log-transforming 0. In addition, we standardized the delays and session numbers prior to model-fitting (Hox et al., 2017). Log-transformed delays were standardized by dividing each delay by the longest log-transformed delay (32 s). Sessions were standardized individually for each rat.
by dividing each session number for a rat by the highest session number completed by that rat (i.e., within-subject standardization; Wang et al., 2019). After standardizing delays and sessions, we centered both predictors by subtracting 0.5 from the standardized values. Choice type was treated as a categorical predictor that was effect coded (initial choice = +1; final choice = -1). This predictor captures how frequently rats defected on their choice of the 150-μL option such that a larger difference between initial and final choice indicates that rats defected more frequently. Finally, intercepts were allowed to vary across rats (i.e., random intercepts for subjects) in the initial and subsequent models (described next).

After fitting the initial GLMM, we examined whether the inclusion of random slope effects significantly improved model fit. Broadly, the inclusion of a random slope effect allows the effect of a predictor to vary for each subject in the model (e.g., change over time with the session predictor), accounting for subject-to-subject variability in the effect of a predictor. We tested whether the inclusion of random slope effects for delay, choice type, and session significantly improved model fit. We added random effects one at a time and retained that effect in the final model if it improved model fit according to a likelihood ratio test (Hox et al., 2017). After including random slope effects, we evaluated the significance of predictors with Wald tests using the car package in R (Fox & Weisberg, 2019; R Core Team, 2019).

To visually assess patterns of choice across time, we also calculated area under the curve (AUC; Myerson et al., 2001) from each session for each rat. Area under the

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5 Standardizing sessions individually allowed us to generate meaningful predicted values for initial and final choices from the first and last session (i.e., when session = -.5 and +.5 after centering). A model in which sessions were standardized by the highest completed session number across rats (i.e., global standardization) produced qualitatively similar results.
curve is a more global measure of choice that is calculated by summing the area under plotted initial or final choice proportions at each delay, given by the following equation:

\[
\sum (x_2 - x_1) \left[ \frac{(y_1 + y_2)}{2} \right]
\]  

Equation 2

where \(x_2\) and \(x_1\) are adjacent delays and \(y_1\) and \(y_2\) are the adjacent proportions for those delays. Area under the curve ranges from 0 to 1 such that higher values correspond to more choices for the larger-later (150-\(\mu\)L) option. We log-transformed the delays as in the GLMM to account for the disproportionate influence that longer delays have in the calculation of AUC (Borges et al., 2016). Some rats omitted all free-choice trials within a block; therefore, we only calculated AUC from sessions in which rats responded during each block (see Table S1 in the supplemental files for more information on trials completed). When initial and final choice AUC are equal, this indicates that a rat initially chose the 150-\(\mu\)L option and waited for that option without a defection response (i.e., without reversing their preference). When initial choice AUC is greater than final choice AUC, this indicates that a rat initially chose the 150-\(\mu\)L option and subsequently defected on that choice (i.e., reversed their preference).

We conducted all analyses in R (R Core Team, 2019). Our data and code are available on the Open Science Framework (OSF; https://osf.io/wup57/?view_only=67ba6fc6bb114fb3b835e9e38621d93c). The GLMMs were conducted using the lme4 package (Bates et al., 2015). Post-hoc contrasts were conducted using the emmeans package (Lenth, 2021).

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6 We did not exclude sessions in which there were few trials (e.g., 1 trial) in a block; however, visual assessments of AUC were similar if we excluded sessions in which there were few trials.
Results

During the increasing-delay DoG task, choice of the larger-later (150-μL) option decreased as the delay to its receipt increased, similar to that typically reported for the increasing-delay task (e.g., Evenden & Ryan, 1996). In addition, we found that rats sometimes initially chose the 150-μL option and defected on that choice in favor of the smaller-immediate (50-μL) option; however, the degree to which rats defected on their choice of the 150-μL option decreased across sessions of the task. To illustrate, Figure 3 shows initial and final choice proportions as a function of delay during the first and last three sessions of the increasing-delay DoG task for each rat. During the first three sessions of the increasing-delay DoG task, rats often initially chose the 150-μL option and subsequently defected on that choice, indicated by the differences between initial and final choice proportions. During the last three sessions of the increasing-delay DoG task, however, when rats initially chose the 150-μL reinforcer, they often waited for that reinforcer, rarely defecting on that choice. To further illustrate these changes over time, Figure 4 shows initial and final choice AUC as a function of session. Similar to initial and final choice proportions, we found that the difference between initial choice AUC and final choice AUC was higher during early sessions of the task; however, across sessions initial choice AUC and final choice AUC became more similar. Next, we discuss the results of the final GLMM which characterizes these effects.
Figure 3
 INITIAL AND FINAL CHOICE PROPORTIONS FROM THE INCREASING-DELAY DOG TASK DURING EXPERIMENT 1

Note. Initial and final choice proportions as a function of delay for each rat (rows) during the first and last 3 sessions of the increasing-delay DoG task. The session number is displayed above each panel. Data points are jittered on the x axis so that all are visible.
Figure 4
*Initial and Final Choice AUC from the Increasing-Delay DoG Task During Experiment 1*

Note. Initial and final choice AUC as a function of session averaged across rats (top-left panel) and for individual rats in increasing-delay DoG task.

As described in the data analysis section, we built the final GLMM by first fitting a full factorial model with random intercepts and subsequently added random slope effects which allowed us to account for the observed individual differences in choice within the model. First, the inclusion of a random slope effect for delay significantly improved model fit and thus this effect was retained in the model, \( \chi^2(2) = 212.38, p < 0.001 \). Including this effect allowed sensitivity to delay to differ for each subject in the model. Next, we included a random slope effect for choice type because doing so
significantly improved model fit, $\chi^2(3) = 402.26, p < .001$. Including the random slope effect for choice type allowed the difference between initial choice and final choice to vary for each subject. Finally, we found that the inclusion of a random slope effect for session significantly improved model fit; therefore, we retained this effect in the model, $\chi^2(4) = 267.83, p < .001$. Including this effect allowed change-over-time in initial and final choice to vary for each subject. After including these random slope effects, we evaluated the significance of predictors with this final GLMM.

Figure 5 shows model predictions from the final GLMM for the first and last session of the increasing-delay DoG task. Similar to the initial and final choice proportions depicted in Figure 3, the likelihood of an initial and final choice for the larger-later (150-μL) option decreased as a function of delay which was supported by the final GLMM according to a significant main effect of delay, $\chi^2(1) = 284.23, p < .001$ (see Table 1). The model did not show a significant main effect for choice type (initial vs. final), $\chi^2(1) = 2.43, p = .12$, nor for session, $\chi^2(1) = 0.76, p = .38$; however, as Figure 5 shows, the difference between initial and final choice was greater at longer delays than at shorter delays, and this difference was greater during the first session than during the last session. The two-way interactions between delay, choice type, and session were significant (see Table 1); however, the finding that the difference between initial and final choice varied as a function of delay and session is best described by the significant three-way interaction between delay, choice type, and session, $\chi^2(1) = 38.79, p < .001$. Thus,

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7 We only show model predictions at the group-level for the first and last session of the increasing-delay DoG task because these sessions correspond to the same sessions (i.e., the first and last session) across all subjects. We include best linear unbiased predictions in the Supporting Information which show model predictions at the individual-subject level for the first and last 3 sessions of the increasing-delay DoG task in this experiment as well as for the GLMM used in Experiment 2.
although rats frequently defected on their choice of the 150-μL option during the initial sessions of the task, these defection responses decreased across sessions of the task.

Figure 5
GLMM Model Predictions for Experiment 1

Note. Predicted probability of an initial and final choice for the larger-later (150-μL) option as a function of delay during the first and last session of the increasing-delay DoG task in Experiment 1. Model predictions were generated from the final GLMM. Error bands represent 95% confidence intervals.

Table 1
Results from the GLMMs on choice data in the increasing-delay DoG task from Experiments 1 and 2

<table>
<thead>
<tr>
<th>Fixed Effects</th>
<th>Experiment 1</th>
<th></th>
<th></th>
<th></th>
<th>Experiment 2</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b</td>
<td>$\chi^2$</td>
<td>df</td>
<td>p</td>
<td>b</td>
<td>$\chi^2$</td>
<td>df</td>
<td>p</td>
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<tr>
<td>Intercept</td>
<td>1.86</td>
<td>13.48</td>
<td>1</td>
<td>&lt;.001</td>
<td>1.22</td>
<td>1.10</td>
<td>1</td>
<td>.29</td>
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<tr>
<td>Log Delay</td>
<td>-11.69</td>
<td>284.23</td>
<td>1</td>
<td>&lt;.001</td>
<td>-15.98</td>
<td>49.08</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Choice Type</td>
<td>0.29</td>
<td>2.43</td>
<td>1</td>
<td>.12</td>
<td>0.06</td>
<td>1.86</td>
<td>1</td>
<td>.17</td>
</tr>
<tr>
<td>Session</td>
<td>-0.43</td>
<td>0.76</td>
<td>1</td>
<td>.38</td>
<td>0.62</td>
<td>19.42</td>
<td>1</td>
<td>&lt;.001</td>
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<tr>
<td>Log Delay × Choice Type</td>
<td>1.28</td>
<td>70.45</td>
<td>1</td>
<td>&lt;.001</td>
<td>0.30</td>
<td>3.02</td>
<td>1</td>
<td>.08</td>
</tr>
<tr>
<td>Log Delay × Session</td>
<td>-6.58</td>
<td>173.05</td>
<td>1</td>
<td>&lt;.001</td>
<td>1.33</td>
<td>5.49</td>
<td>1</td>
<td>.02</td>
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<tr>
<td>Choice Type × Session</td>
<td>-0.20</td>
<td>4.57</td>
<td>1</td>
<td>.03</td>
<td>-0.07</td>
<td>0.22</td>
<td>1</td>
<td>.64</td>
</tr>
<tr>
<td>Log Delay × Choice Type × Session</td>
<td>-2.69</td>
<td>38.79</td>
<td>1</td>
<td>&lt;.001</td>
<td>0.17</td>
<td>0.09</td>
<td>1</td>
<td>.77</td>
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<table>
<thead>
<tr>
<th>Random Effects</th>
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<th>SD</th>
<th>Variance</th>
<th>SD</th>
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</thead>
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<td>Subject</td>
<td>1.81</td>
<td>1.34</td>
<td>5.86</td>
<td>2.42</td>
</tr>
<tr>
<td>Log Delay</td>
<td>3.22</td>
<td>1.80</td>
<td>20.90</td>
<td>4.57</td>
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<tr>
<td>Choice Type</td>
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<td>0.49</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Session</td>
<td>1.68</td>
<td>1.30</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

-Not included because model failed to converge
Figures 3 and 5 show that although both initial and final choices for the larger-later (150-µL) option decreased across sessions of the increasing-delay DoG task, initial choices for the larger-later option tended to decrease more than final choices for that option. We explored this finding further by conducting a simple slopes analysis which compared the session slope effect for initial choice against the session slope effect for final choice, at each delay. In other words, we sought to determine whether the decreases in defection responses across sessions were due to decreases in initial choices for the 150-µL reinforcer or to increases in waiting for the 150-µL reinforcer (i.e., final choices). At the 8-, 16-, and 32-s delays, this analysis revealed that both initial and final choices for the 150-µL option decreased across sessions, but initial choices for the 150-µL option decreased at a faster rate than final choices (all $p$s < .001 Bonferroni-corrected; see Table 2). Thus, rats primarily showed decreases in defection responses across time due to decreases in initial choice of the larger-later (150-µL) option.

### Table 2

*Results of simple slopes analysis from Experiment 1*

<table>
<thead>
<tr>
<th>Delay (s)</th>
<th>$\omega_{\text{Initial}}$</th>
<th>$\omega_{\text{Final}}$</th>
<th>$z$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>-0.27</td>
<td>-0.08</td>
<td>0.90</td>
<td>&gt;.99</td>
</tr>
<tr>
<td>8</td>
<td>-1.83</td>
<td>-0.73</td>
<td>7.66</td>
<td>&lt;.001</td>
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<tr>
<td>16</td>
<td>-3.51</td>
<td>-1.44</td>
<td>10.25</td>
<td>&lt;.001</td>
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<tr>
<td>32</td>
<td>-5.27</td>
<td>-2.18</td>
<td>9.13</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

$p$-values are Bonferroni-corrected

$\omega$ represents the simple slope for session

### Discussion

The finding that rats would defect on their choice of a delayed larger amount of sucrose solution in the increasing-delay DoG task replicates Reynolds et al.’s (2002) finding that rats would defect on their choice of a delayed larger amount of water in an adjusting-amount delay of gratification task. These findings support Reynolds et al.’s
conclusion that other processes (e.g., inhibitory control) may be involved in maintaining preference for a delayed outcome after it is chosen. However, we also found that the degree to which rats defected on their choice of the larger-later (150-μL) option decreased over time, primarily due to decreases in initial choices of that option. Although the decreases in defection responses occurred at different rates for different rats (see Figure 4), defection responses were rare for all rats by the end of the task (see Figure 3). Thus, if we focus on behavior in the last sessions of the increasing-delay DoG task, our results are consistent with predictions from hyperbolic discounting in which preference should be maintained for a larger-later reward after it is chosen (i.e., no preference reversals).

The decrease in defection responses across sessions was unexpected; however, there is a model of impulsive behavior that predicts decreases in defection responses across time as a function of changes in initial choices. Specifically, the Feedback Model of Delay-Related Impulsive Behavior (Reynolds & Schiffbauer, 2005) predicts that individuals will adjust their initial choices for a larger-later reward after exposure to a delay of gratification task based on their experience of withholding the defection response. According to the model, a feedback (i.e., learning) process influences future decisions to avoid unnecessary waiting. That is, rather than choosing the larger-later reward, waiting, and then subsequently defecting on that choice to obtain the smaller-immediate reward (a failure in inhibitory control), an individual could receive the smaller-immediate reward sooner by just choosing it initially. Our data from Experiment 1 are consistent with the Feedback Model in that rats transitioned from obtaining the smaller-immediate (50-μL) reinforcer following a defection response to obtaining the 50-
μL reinforcer by initially choosing it, a transition that would reduce the wait time for that reinforcer. Although not presented here, defection latencies tended to decrease across sessions (see Supporting Information), which is also consistent with a pattern of behavior associated with reducing wait time for the smaller-immediate option. Thus, although we did not expect defection responses to decrease across sessions in the increasing-delay DoG task, this finding is consistent with predictions of the Feedback Model of Delay-Related Impulsive Behavior.

Experiment 2

In Experiment 2, rats completed an intertemporal choice task (ITC), hereafter referred to as an increasing-delay ITC task, prior to completing the increasing-delay DoG task. These data allowed us to evaluate a prediction of the Feedback Model of Delay-Related Impulsive Behavior regarding why defection responses may decrease across sessions of a delay of gratification task (Reynolds & Schiffbauer, 2005). According to the model, experience withholding a defection response is necessary for changes in initial choice to occur, allowing individuals to avoid unnecessary waiting. For rats in Experiment 2, all aspects of the increasing-delay ITC task were the same as the increasing-delay DoG task; however, after a rat chose the delayed sucrose reinforcer, the rat could not defect on its choice in favor of the smaller-immediate sucrose reinforcer. Thus, rats in this experiment first completed an ITC task in which all aspects of the task were identical to the DoG task except the availability of the defection response. After completing the ITC task, rats completed the DoG task which included the availability of the defection response as in Experiment 1. If experience withholding the defection response is necessary for defection responses to decrease, we would expect similar
patterns of responding on the increasing-delay DoG task as those observed in Experiment 1. That is, we would expect rats that had completed the ITC task before the DoG task to show a high number of defection responses initially on the DoG task, but fewer defection responses across time as they accrued experience in the DoG task.

**Method**

**Subjects**

Six experimentally naïve male Wistar rats were randomly assigned to Experiment 2 from the total of 13, but ultimately two rats were excluded for failure to discriminate amount (details in Procedure). All other details, including the supplier, housing conditions, feeding regimen, and institutional approval were as in Experiment 1. We increased food restriction for one rat (DG 14), maintaining it at 80% of its estimated free-feeding weight, because this rat omitted a high number of trials during the increasing-delay ITC task. This rat continued to omit a high number of trials, however, across both tasks even under the increased food restriction.

**Apparatus and Materials**

We used the same operant conditioning chambers, materials, and programming software as in Experiment 1.

**Procedure**

We conducted initial training and amount-discrimination training sessions as in Experiment 1. We implemented remedial training for one rat (DG29) that did not choose the larger (150-μL) option on at least 80% of trials and showed no increasing trend in choice of the 150-μL option during four sessions of amount-discrimination training. This

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8 Free-feeding weights during Experiment 2 were based on growth curves provided by the supplier as in Experiment 1.
rat required additional remedial training sessions and was removed from the experiment because it did not meet the 80% choice criterion (i.e., failed to discriminate amount) after 18 total remedial training sessions, leaving 5 rats in the experiment after this initial stage. After completing amount-discrimination training, rats began the increasing-delay ITC task (described next), followed by the increasing-delay DoG task.

**Tasks.** Rats first experienced the increasing-delay ITC task which was structured the same as the increasing-delay DoG task except that a rat could not reverse its preference during the delay to the larger-later sucrose reinforcer. That is, if a rat selected the larger-later (150-μL) option, both side levers retracted immediately, leaving only the inactive lever available during the delay (see Figure 2, bottom panel). After the delay elapsed, the inactive lever retracted and 150 μL of sucrose solution was delivered. Thus, in the increasing-delay ITC task, if a rat chose the 150-μL option, that rat could not defect on its choice in favor of the smaller-immediate (50-μL) option whereas in the increasing-delay DoG task, a rat could choose the 150-μL option and defect on that choice in favor of the 50-μL option. One rat (DG19) consistently chose the 150-μL option on less than 80% of trials in the 0-s delay block when delays were introduced during the other blocks of the increasing-delay ITC task. This rat was thus removed from the experiment, leaving a total of 4 rats that completed Experiment 2. Rats finished the increasing-delay ITC task based on the behavioral stability and fixed-time criteria described in Experiment 1. After completing the increasing-delay ITC task, rats were returned to amount-discrimination training. After completing amount-discrimination training as described above, rats were transitioned to the increasing-delay DoG task for 30 sessions. More sessions were
conducted for rats who omitted a large number of trials (>10%), until they had 30 complete sessions.9

**Data Analysis**

We used the same analytical approach as in Experiment 1. Specifically, we used a generalized linear mixed model (GLMM) to analyze choice data (i.e., initial and final choices for the 150-μL option) from the increasing-delay DoG task. In addition, we calculated AUC using Equation 2 for visual display. Although we present data from the increasing-delay ITC task, we only performed inferential statistical analyses on data from the increasing-delay DoG task. All other analytical details were the same as in Experiment 1.

**Results**

Figure 6 shows that, as in Experiment 1, choice of the larger-later (150-μL) option decreased as the delay to its receipt increased in the increasing-delay ITC task and in the increasing-delay DoG task. Unlike Experiment 1, however, rats rarely defected on their initial choice of the 150-μL option during the increasing-delay DoG task, indicated by the small differences between initial and final choice proportions during the first 3 sessions of the task. Similarly, Figure 7 shows that initial and final choice AUC were similar throughout the increasing-delay DoG task, indicating that rats rarely defected on their initial choice of the 150-μL option. Next, we report the results of the final GLMM which characterizes these effects.

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9 One rat (DG6) showed an increasing number of omissions across sessions of the increasing-delay DoG task. These omissions tended to occur at longer delays, which we thought could have been indicative of satiation. Therefore, we temporarily reduced the amount of the smaller-immediate and larger-later options by half (i.e., 25 and 75 μL, respectively). Reducing the amount of sucrose did not reduce omissions; therefore, we returned the amounts of both options to the original amounts (50 and 150 μL) for this rat for the remainder of the task. The data with the reduced amounts were not included in the analyses described below but are available on OSF.
Figure 6
Initial and Final Choice Proportions from the Increasing-Delay ITC and DoG Tasks During Experiment 2

Proportion Larger Later Option

Last 3 ITC Sessions
First 3 DoG Sessions

Delay (s)

Note. Initial and final choice proportions as a function of delay for each rat (rows) during the last 3 sessions of the increasing-delay ITC task and the first 3 sessions of the increasing-delay DoG task. The session number is displayed above each panel. Data points are jittered on the x-axes so that all are visible. Missing datapoints represent blocks of trials in which a rat did not respond during that block.
Figure 7
Initial and Final Choice AUC from the Increasing-Delay ITC and DoG Tasks During Experiment 2

Note. Initial and final choice AUC as a function of session averaged across rats (top-left panel) and for individual rats during the last 10 sessions of the increasing-delay ITC task and all sessions of the increasing-delay DoG task.

As in Experiment 1, we built the final GLMM by first fitting a full factorial model with random intercepts and subsequently added random slope effects to account for the observed individual differences in the model. We included a random slope effect for delay because doing so significantly improved model fit, $\chi^2(2) = 165.07, p < 0.001$. This was the only random slope effect included in the model; thus, sensitivity to delay was
allowed to vary for each subject in the final model. Next, we evaluated the significance of predictors using this model.

Figure 8 shows model predictions from the final GLMM for the first and last session of the increasing-delay DoG task. Similar to the initial and final choice proportions depicted in Figure 6, the likelihood of an initial and final choice for the larger-later (150-μL) option decreased as the delay to its receipt increased, which was captured by the final model with a significant main effect of delay, $\chi^2(1) = 49.08, p < .001$ (see Table 1). As Figure 8 also shows, the model predicted little difference between initial and final choices for the 150-μL option, as indicated by no main effect of choice type, $\chi^2(1) = 1.86, p = .17$, and no significant two- or three-way interactions involving choice type (all $p > .05$; see Table 1).

**Figure 8**

*GLMM Model Predictions for Experiment 2*

*Note.* Predicted probability of an initial and final choice for the larger-later (150-μL) option as a function of delay during the first and last session of the increasing-delay DoG task in Experiment 2. Model predictions were generated from the final GLMM. Error bands represent 95% confidence intervals.
The final model showed that initial and final choices for the larger, 150-μL option increased across sessions according to a significant main effect of session, $\chi^2(1) = 19.42, p < .001$, and a significant delay × session interaction, $\chi^2(1) = 5.49, p = .02$. The delay × session interaction indicates that increases in initial and final choices for the 150-μL option tended to occur at longer delays. These findings should be interpreted cautiously, however, because as Figure 8 shows, these increases in choices for the larger, 150-μL option across sessions were small. Furthermore, Figure 7 indicates that these increases in choice of the 150-μL option according to the model may be largely driven by a single rat (DG5). Overall, however, we found that after having first completed the increasing-delay ITC task, rats rarely made defection responses in the increasing-delay DoG task.

**Discussion**

The findings from Experiment 2 are inconsistent with predictions from the Feedback Model of Delay-Related Impulsive Behavior (Reynolds & Schiffbauer, 2005). Specifically, the Feedback Model predicts that prior experience in withholding a defection response is necessary for defection responses to decrease via a feedback process. However, rats that experienced an intertemporal choice task, which had no possibility of making a defection response, also made few defection responses when this response became available. Thus, our data suggest that a feedback process, which influences behavior based one’s prior experience making defection responses, may not be necessary for rats to adjust their behavior in a delay of gratification task to avoid unnecessary waiting, as the Feedback Model suggests.

Data from Experiment 2 are inconsistent with the Feedback Model; however, it is important to recognize the limitations of this experiment. First, although rats were
randomly assigned to Experiment 1 and 2, it is possible that the rats in Experiment 2 were simply rats that rarely make defection responses. This possibility is important to consider because some rats in Experiment 1 showed very few defection responses (e.g., DG1 & DG7). Without a control group that did not experience the increasing-delay ITC task in Experiment 2 (i.e., that remained experimentally naive during the first condition), we cannot rule out this possibility. However, even among the rats that rarely made defection responses in Experiment 1, we observed a decreasing pattern of defection responses across time (see Figure S1 in the Supporting Information for a visual display of defection counts between rats in Experiments 1 and 2). Thus, if the rats in Experiment 2 simply represent a sample of rats that rarely defect on their choice of a larger-later reinforcer, we still should have observed the decreasing pattern of defection responses across time in the increasing-delay DoG task, but we did not.

Another limitation of Experiment 2 is that some rats (e.g., DG6 & DG14) omitted a high number of trials (i.e., did not respond within the 10-s limited hold; see Table S1). Omissions tended to occur during forced-choice trials at longer delays, indicating that rats may have avoided exposure to longer delays (Peck et al., 2020; see also Stein et al., 2015). If omissions occurred because the delays were aversive, it is reasonable to assume that the rats would have chosen the smaller-immediate reward on the subsequent free-choice trials, but they did not have an opportunity to choose because they did not complete the forced-choice trials. Future research could modify the tasks in our study to address this issue by allowing rats to transition to free-choice trials following a maximum number of omissions on forced-choice trials.
General Discussion

Overall, our results showed that rats would defect on their choice of a larger-later (150-μL) sucrose reinforcer to obtain a smaller-immediate (50-μL) sucrose reinforcer; however, the frequency with which rats defected on their choices for the larger-later reinforcer depended on their prior experience. In Experiment 1, initially, rats frequently defected on their choice of the 150-μL option in the increasing-delay DoG task; however, defection responses decreased across sessions of that task. The decrease in defections over time occurred because rats transitioned from obtaining the smaller-immediate reinforcer following a defection response to obtaining that reinforcer by initially choosing it. In Experiment 2, rats that first completed an intertemporal choice (ITC) task rarely defected on their choice of the larger-later (150-μL) option when transitioned to the increasing-delay DoG task. Thus, although rats sometimes reversed their preference from the larger-later sucrose reinforcer, completing an extended number of sessions on the delay of gratification task as well as first completing an intertemporal choice task prior to the delay of gratification task were both associated with fewer preference reversals.

The finding that rats would make defection responses (i.e., preference reversals) could indicate that processes other than delay discounting are required for preference of a delayed outcome to persist after choosing that outcome. According to models of delay discounting (e.g., hyperbolic discounting), we would not expect defection responses to occur, because after choosing a larger-later reward, the value of that reward should continue to increase whereas the value of the smaller-immediate reward should remain the same (recall Figure 1B). Reynolds et al. (2002) suggest that defection responses could represent failures in inhibitory control, a form of impulsive behavior that is unrelated to
delay discounting (Broos et al., 2012). This interpretation of defection responses is consistent with research showing that greater inhibitory control in response inhibition tasks (e.g., go/no-go task) is associated with withholding a defection response in a delay of gratification task for children (Carlson et al., 2014; Yu et al., 2016). Thus, defection responses in delay of gratification tasks such as our within-session increasing-delay task could be the result of failures in inhibitory control.10

Although rats in our study defected on their choice of a larger-later sucrose reinforcer, the degree to which they did so decreased as a function of the number of sessions completed on the increasing-delay DoG task (Experiment 1). Therefore, defection responses early in the task could simply represent behavior in transition to a steady state (Perone, 1991) in which defections rarely occur, a state that would be consistent with hyperbolic discounting. Although defection responses were rare after an extended number of sessions on the increasing-delay DoG task, this finding does not preclude a role of inhibitory control in behavior on delay of gratification tasks. According to the Feedback Model of Delay-Related Impulsive Behavior (Reynolds & Schiffbauer, 2005), defection responses should decrease across sessions in a delay of gratification task because these responses are associated with increased wait-time for the smaller-immediate reward. Our findings from Experiment 1 were consistent with the Feedback Model in that the frequency of defection responses decreased over time.

An important prediction based on the Feedback Model, however, is that experience withholding the defection response causes the changes in initial choices that subsequently allows individuals to avoid unnecessary waiting (Reynolds & Schiffbauer,

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10 It should be noted that although defection responses in the increasing-delay DoG task may be related to inhibitory control, initial choices are unrelated to inhibitory control (e.g., Broos et al., 2012).
2005). Experiment 2 allowed us to test this prediction using rats that first experienced an intertemporal choice task (i.e., the increasing-delay ITC task) that was identical to the increasing-delay DoG task, but without the availability of the defection response. After completing the increasing-delay ITC task, rats showed few defection responses when they first began the increasing-delay DoG task, indicating that experience withholding the defection response is not necessary for defection responses (i.e., preference reversals) to decrease. That is not to say that inhibitory control is not involved in withholding a defection response; however, our results are inconsistent with the Feedback Model’s prediction that initial choices in a delay of gratification task change across sessions specifically as a function of experience withholding the defection response. Future research is necessary to further understand the potential role that inhibitory control may have in maintaining preference for a larger-later outcome in delay of gratification tasks.

Our findings are, however, consistent with McGuire and Kable’s (2013) Normative Perspective, which does not include a role of inhibitory control in maintaining preference for a delayed outcome. Specifically, before an individual learns the delays to an outcome, estimates of the delay may change throughout the delay period as it elapses. If an updated estimate is longer than a previous estimate (e.g., when the initial choice was made), a preference reversal could occur if the discounted value of the larger-later reward falls below the value of the smaller-immediate reward. However, as an individual learns the delays to an outcome, we would not expect estimates of the delay to further change. Therefore, after an individual initially chooses a larger-later reward, we would expect that individual to maintain their preference for that reward during the delay period because the discounted value of the larger-later reward would remain above the value of the
smaller-immediate reward (e.g., Figure 1B). Thus, according to the Normative Perspective, we would expect defection responses to decrease as a function of learning the delays to a larger-later reward.

Our data are consistent with the Normative Perspective if we assume that completing an extended number of sessions on the increasing-delay DoG task and the increasing-delay ITC task were associated with learning the delays to the larger-later (150-μL) sucrose reinforcer. For example, in Experiment 1, the decrease in defection responses across sessions of the increasing-delay DoG task could be the result of learning the delays to the 150-μL option as rats accumulated experience on the task. Similarly, in Experiment 2, the relatively few defection responses during sessions at the beginning of the increasing-delay DoG task could be the result of learning the delays to the 150-μL option during the prior increasing-delay ITC task. Thus, our finding that completing an extended number of sessions on a delay of gratification task and an intertemporal choice task were both associated with fewer defection responses could be the result of learning the delays to the larger-later reward (referred to as temporal learning; McGuire & Kable, 2013). Time-based interventions (e.g., exposure to delayed rewards) have been shown to influence choice of larger-later rewards in rats (e.g., Smith et al., 2015); however, the causal relation between timing and choice in intertemporal choice tasks is unclear (Rung et al., 2018; Smith et al., 2022). Therefore, future research should further explore the role of temporal learning in intertemporal choice tasks in addition to delay of gratification tasks.

Although our data are consistent with McGuire and Kable’s (2013) Normative Perspective, alternative explanations should be considered. For example, it is possible
that defection responses during sessions at the beginning of the increasing-delay DoG task in Experiment 1 were functionally similar to responses during forced-choice trials for the smaller-immediate (50-μL) option because after a rat chose the larger-later (150-μL) option during a free-choice trial, the stimuli present in the operant chamber were the same as those during a smaller-immediate forced-choice trial. That is, in both situations, only the inactive lever and the lever for the smaller, 50-μL option were available (see Figure 2, top panel). Thus, defection responses during the delay to the larger, 150-μL option could have represented a lack of stimulus control by trial type. Moreover, the decrease in defection responses across time could have represented the development of the discrimination between smaller-immediate forced-choice trials and free-choice trials in which the rat chose the larger-later option.

Although defection responses during Experiment 1 could have represented a lack of stimulus control, we find this possibility unlikely because of the results of Experiment 2. During Experiment 2, rats had prior experience on an intertemporal choice task in which the defection response was *not* available (see Figure 2, bottom panel). Thus, rats in Experiment 2 could not have developed stimulus control between smaller-immediate forced-choice trials and free-choice trials in which the larger-later (150-μL) option was chosen during the increasing-delay ITC task. Therefore, when rats transitioned to the increasing-delay DoG task, we should expect a high number of defection responses initially because the availability of the defection response would have resembled the option during smaller-immediate forced-choice trials. Instead, however, rats made relatively few defection responses, with no decreasing trend, as would be expected if they were developing stimulus control. Thus, we find it unlikely that defection responses in
Experiment 1 represented a lack of stimulus control between smaller-immediate forced-choice trials and free-choice trials in which the larger-later option was chosen.

Although the increasing-delay DoG task could provide important insights regarding the processes involved in delay of gratification, it is important to recognize some limitations of the task. First, within-session increasing-delay procedures have been shown to produce perseverative responding after extended exposure on such tasks (e.g., Pitts & McKinney, 2005). This can be problematic because choice may be controlled by factors (e.g., elapsed time in the session) other than the task parameters (i.e., amount of and delay to the larger-later reinforcer). To identify perseverative responding, researchers using the increasing-delay DoG task could include occasional probe sessions in which the delay to the larger-later option is 0 s across all blocks of trials within the probe session. In addition, because the delays and amounts were standardized across rats, this can make procedures such as ours more susceptible to ceiling and floor effects (e.g., DG1 & DG24). To avoid such ceiling and floor effects, the task could be modified to identify individual delays for each rat that produce a moderate number of defection responses. Finally, although not a limitation of the task itself, we only evaluated whether preference reversals would occur in male rats. To further validate this task and to evaluate potential sex-differences (although see Duckworth et al., 2013 & Forzano et al., 2011), future research should include both male and female rats as subjects (National Institutes of Health, 2015).

Despite the limitations, this study provides the foundation for using a within-session increasing-delay task to test delay of gratification in rats. Although the delay of gratification task is similar to other standard intertemporal choice tasks (e.g., Evenden &
Ryan, 1996), the inclusion of a defection response allows researchers to observe a form of preference reversal that is not predicted by hyperbolic discounting. Using the delay of gratification task, we found that defection responses rarely occurred after 1) rats completed an extended number of sessions on the delay of gratification task or 2) after rats first completed an intertemporal choice task prior to the delay of gratification task. These findings have important implications for the processes involved in this form of preference reversal. Future research will be necessary to determine the possible role, if any, of inhibitory control as well as temporal learning in the occurrence of defection responses as a form of preference reversal. Importantly, the study of preference reversals using a preclinical rat model, as in the present study, could provide important insights regarding the processes involved in this form of preference reversal among people. Because this form of preference reversal could have implications for human health (Michaelson & Munakata, 2020; Mischel et al., 2011; Reyes-Huerta, 2018), such studies will be important for developing interventions to address these maladaptive behaviors in humans.
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CHAPTER III
TEMPORAL EXPECTATIONS IN DELAY OF GRATIFICATION

Abstract

We examined how temporal expectations may influence preference reversals in a delay of gratification task for rats. To do this, we pre-exposed rats to the delays associated with a larger-later reinforcer from a delay of gratification task and examined how pre-exposure influenced defections (i.e., preference reversals) in the delay of gratification task. In Experiment 1, we employed response-initiated fixed-time schedules during exposure training but found that the training procedure did not affect defections in the delay of gratification task, potentially indicating that temporal expectations do not influence these preference reversals. In Experiment 2, we modified the pre-exposure procedure by employing response-initiated fixed-interval schedules so that we could measure temporal control of behavior. Using this modified procedure, we found evidence of temporal control during pre-exposure training and that rats who experienced delays during training tended to make fewer defection responses than a control group of rats who did not experience delays during training. These findings suggest that temporal expectations influence preference reversals in a delay of gratification task; however, they also highlight methodological considerations (e.g., schedule of reinforcement) when studying this form of preference reversal. Importantly, these findings provide a number of future directions for research on these preference reversals.

Keywords: intertemporal choice, delay of gratification, preference reversals, linear mixed modeling, rat
Introduction

Delay discounting is the process by which outcomes lose value as a function of their delay and is often used to characterize patterns of intertemporal choices in both humans and non-human animals (Rachlin et al., 1991; see also Madden & Johnson, 2010; Odum, 2011). For example, the rapid loss in value of a delayed outcome (i.e., steep delay discounting) is characterized by a pattern of choices for smaller-sooner over larger-later rewards. Steep discounting has received widespread attention because such patterns of decision-making are related to numerous maladaptive behaviors among people (Bickel et al., 2012). For example, steep discounting is associated with the use of tobacco cigarettes (Friedel et al., 2014; Mitchell, 1999), e-cigarettes (DeHart et al., 2020), heroin (Madden et al., 1997), cocaine (Coffey et al., 2003), and methamphetamine (Ballard et al., 2015; Hoffman et al., 2006; for a review see MacKillop et al., 2011). In addition, steep delay discounting is associated with alcohol misuse (Field et al., 2007; Vuchinich & Simpson, 1998), problematic gambling (Cosenza et al., 2017; Ledgerwood et al., 2009), and texting while driving (Hayashi et al., 2016). Although there is a strong correlation between degree of discounting and health behavior, it is important to recognize that this research does not confirm a causal relation between steep discounting and these health-related behaviors (Rung & Madden, 2018). Moreover, and central to the present study, other processes are involved in intertemporal choice that likely contribute to these behaviors (Bailey et al., 2021).

The purpose of this study was to explore a facet of intertemporal choice related to delay discounting: preference reversals. There are multiple forms of preference reversal; however, we will focus on the form characterized by shifts in preference from a larger-
later reward to a smaller-immediate reward after an initial choice of the larger-later reward (Haynes & Odum, 2022; McGuire & Kable, 2013; Reynolds et al., 2002).\footnote{Other forms of preference reversal exist such as the shift in preference from a larger-later reward to a smaller-sooner reward when both outcomes become temporally proximal (Green et al., 1994). We refer interested readers to Haynes and Odum (2022), McGuire and Kable (2013), and Reynolds et al. (2002), who provide detailed descriptions of the distinction between these forms of preference reversal.} For example, when a person makes a choice to quit smoking cigarettes, they are often confronted with multiple opportunities to ‘defect’ on that choice and begin smoking again (i.e., relapse). In this situation, many of the benefits associated with abstaining from cigarettes are delayed (e.g., improved lung function; American Lung Association [ALA], 2020), whereas the gratification from smoking is immediate. For cigarette smoking, a preference reversal would be characterized by a shift in preference from the benefits of abstaining from cigarettes to the gratification from smoking now. The high relapse rates among individuals who smoke indicate that these preference reversals may be common. For example, people who are able to quit smoking average more than 30 unsuccessful attempts before long-term abstinence (Chaiton et al., 2016).

Although preference reversals are related to intertemporal choice, models of delay discounting do not predict this type of preference reversal. For example, Figure 1A shows the value of a smaller-immediate and larger-later reward as a function of delay according to the hyperbolic discounting model (Mazur, 1987), given by the following equation:

$$V = \frac{A}{1 + k \times D}$$

where $V$ is the discounted value of a delayed outcome, $A$ is the amount of the outcome, $k$ is a free parameter describing the degree of discounting, and $D$ is the delay to the outcome. At Time 1, the discounted value of the larger-later reward is higher than the
value of the smaller-immediate reward and thus, the larger-later reward is initially chosen. After this initial choice, the value of the larger reward increases across time (i.e., as the delay to its receipt decreases) and the value of the smaller reward remains constant at a lesser value across this time. Although we present predictions based on hyperbolic discounting, these predictions are also true of other models of delay discounting (e.g., exponential discounting) that assume the value of a smaller-immediate reward remains constant throughout the delay to a larger-later reward (McGuire & Kable, 2013). As Figure 1A shows, the hyperbolic discounting model predicts that when an individual chooses a larger-later reward over a smaller-immediate reward, preference for that larger reward should be maintained throughout the delay to its receipt.

Figure 1
Preference Reversals Based on Hyperbolic Discounting

Note. Value of a smaller-immediate and larger-later reward as a function of time during the delay to the larger reward. The discounted value of the larger-later reward (solid line)
was calculated according to the hyperbolic discounting model (Equation 1). The immediate availability of the smaller reward during the delay is depicted by multiple black bars. At Time 1, the larger-later reward is chosen over the smaller-immediate reward because the larger reward has higher value than the smaller reward. Top panel (A): Preference for the larger-later reward remains constant during the delay to its receipt. Bottom panel (B): Preference shifts from the larger-later reward to the smaller-immediate reward at Time 2 because the expected delay to the receipt of the larger reward shifts to a longer delay (Time 3).

However, prior research shows that children and rats will ‘defect’ (i.e., reverse their preference) on their choices of a larger-later reward. These findings are inconsistent with hyperbolic discounting and indicate that other processes besides delay discounting may be at work (Forzano et al., 2011; Haynes & Odum, 2022; Reynolds et al., 2002). One such process could be changes in when the larger-later reward is expected (i.e., changes in temporal expectations; McGuire & Kable, 2013; Rachlin, 2000). For example, Rachlin speculated that when the delay to a larger-later reward is unpredictable, a person’s estimates of that delay may shift while they are waiting for that reward (see also McGuire & Kable, 2013). When these estimates shift during the delay to a larger-later reward, the discounted value of that reward should shift as well. For example, Figure 1B shows the value of a smaller-immediate and larger-later reward, with the discounted value of the larger reward depicted according to two different delays. If the larger-later reward is expected at Time 2 and an initial choice is made at Time 1, then the discounted value of the larger-later reward is above that of the smaller-immediate reward and thus, the larger reward is chosen. If, however, the larger-later reward is delivered at Time 3, estimates of the delay to that reward should change when it is not received at Time 2. In this circumstance, if the larger-later reward is now expected at Time 3, the discounted value of that reward should now fall below that of the smaller-immediate reward and
preference should shift in favor of the immediate alternative. Thus, changes in temporal expectations represent a potential process by which preference may shift from a larger-later reward to a smaller-immediate reward after an initial choice of that larger reward.

According to their ‘Normative Perspective’, McGuire and Kable (2013) suggest that temporal expectations can be acquired based on one’s prior experiences with a delayed outcome, and that such experiences should systematically influence how frequently these preference reversals occur. An earlier study by McGuire and Kable (2012) illustrates and supports these predictions. Participants recruited from the community completed a task in which, on each trial, they could wait and earn a larger amount of money after a delay or defect and earn a smaller amount of money immediately. Real money was used, and participants were given a fixed amount of time to complete the task; thus, participants could maximize earnings by waiting or defecting depending on the distribution of delays. For one group of participants, the delays followed a uniform distribution in which the maximizing strategy was to wait on most trials, whereas for the other group, the delays followed a heavy-tailed distribution (i.e., a distribution of very short & very long delays) in which the maximizing strategy was to defect on many of the trials. McGuire and Kable predicted that participants in both groups would show similar patterns of waiting and defecting initially, because they would have little experience with their respective delay-distributions. However, patterns of waiting and defecting were predicted to change according to the maximizing strategy for that distribution as participants gained experience with the task. Consistent with these predictions, participants across both groups showed similar patterns of waiting and defecting initially, but with experience, their patterns of waiting and defecting matched
the maximizing strategy. Thus, methods that influence temporal expectations (e.g., experience with different delay-distributions) may influence how frequently preference reversals occur.

Findings from a study by Haynes and Odum (2022) with rats pressing a lever for food are also consistent with McGuire and Kable’s (2013) Normative Perspective. Haynes and Odum used an increasing-delay delay of gratification (DoG) task to measure defection responses (i.e., preference reversals) among rats that were naïve to the delays in the DoG task (Experiment 1). Among these rats, they found that defection responses decreased across time with experience on the DoG task. It is possible that experience on the task allowed rats to learn the delays to the larger option. After the rats learned the delays, we would expect defection responses to be rare according to the Normative Perspective because there should be no changes in the expected delay to the larger option after rats chose it. In the same study, Haynes and Odum also found that another group of rats rarely defected on their choice of the larger-later option during the DoG task after having completed an increasing-delay intertemporal choice (ITC) task (Experiment 2). Importantly, the ITC task had the same delay progression as the DoG task. Therefore, rats may have learned the delays to the larger option during the ITC task, generalized this learning to the DoG task, and rarely defected because there were no changes in the expected delay to that option during the DoG task.

Behaviorally, we can describe decreases in defection responses as a function of experience with a delay progression as the development of temporal control. First, according to the Normative Perspective, we could assume that defection responses are functionally similar to initial choices for a smaller-immediate reward because both
responses occur as a function of the smaller reward having higher value than the larger-later reward (McGuire & Kable, 2013). Rats that are naïve to the delays to a larger-later reward may frequently defect because their initial choices are not under temporal control by those delays. As rats gain experience on the task, temporal control may develop and rats may transition from choosing the larger-later option, and defecting on that choice, to instead choosing the smaller-immediate option from the outset. The results of Haynes and Odum (2022) are consistent with this interpretation because not only did rats show fewer defection responses as a function of experience with the delays to the larger-later option, they did so by initially choosing the smaller option more frequently. Overall, the results from Haynes and Odum suggest that experience with the delay progression from a delay of gratification task can influence preference reversals in that task in a manner that is consistent with the Normative Perspective.

In the present set of experiments, we explored how experience with the delays associated with a larger-later reward influences preference reversals in a preclinical rat model. Preclinical rat models are particularly well-suited for studying the processes involved in decision-making (e.g., temporal expectations) because of the high level of experimental control that can be obtained (Kalenscher & van Wingerden, 2011). Across two experiments, we exposed rats to delay progressions (cf. Renda et al., 2016; Smith et al., 2015) and examined the effect of pre-exposure training on preference reversals in a delay of gratification task. The goal of these experiments was to determine whether rats would generalize temporal control by the larger-later reinforcer delays from exposure training to the delay of gratification task. If this generalization occurred, we predicted that rats pre-exposed to the same delays as the delay of gratification task would rarely
defect on their choice of the larger-later reinforcer during that task. Thus, the present set of experiments allow us to test and extend predictions by Rachlin (2000) and McGuire and Kable (2013) regarding preference reversals that are characterized by shifts in preference from a larger-later reward to a smaller-immediate reward after an initial choice of the larger reward.

**Experiment 1**

In this experiment, we examined how pre-exposure to two different larger-later reinforcer delay progressions influence preference reversals (i.e., defection responses) in a delay of gratification (DoG) task. For one group of rats, the pre-exposure delay progression followed an increasing delay progression that was identical to that of the DoG task. For this group of rats, we predicted that pre-exposure training would provide rats the opportunity to learn the increasing delay progression and that this learning would generalize to the DoG task. If generalization occurred, we anticipated that rats in this group would rarely defect on their choice of the larger-later reinforcer during the DoG task because temporal expectations, and thus preferences, regarding the larger option should be stable after it was chosen. For another group of rats, the pre-exposure delay progression followed a variable delay progression (Fleshler & Hoffman, 1962) with a mean equal to the mean of the progression used in the DoG task. For this group of rats, we predicted that pre-exposure training would *not* provide rats the opportunity to learn the increasing delay progression. Thus, we anticipated that rats in this group would frequently defect on their choice of the larger-later reinforcer during the DoG task because temporal expectations, and thus preferences, regarding the larger option should be more likely to shift after it was chosen. Overall, we expected the frequency with which
rats would defect on their choice of the larger-later reinforcer to be consistent with predictions by Rachlin (2000) and from McGuire and Kable’s (2013) Normative Perspective.

Method

Subjects

All procedures were approved prior to the beginning of the experiment by the university’s Institutional Animal Care and Use Committee (IACUC Protocol 10095). We used 16 experimentally naïve Wistar rats obtained from Charles River Laboratories, aged approximately 45 days upon arrival. We included an equal number of male ($n = 8$) and female ($n = 8$) rats; there is no evidence of a sex-difference in preference reversals in humans (e.g., Duckworth et al., 2013; Forzano et al., 2011; National Institutes of Health, 2015). Subject IDs correspond to the sex of the rat such that rats with ID numbers beginning with 1 or 2 (e.g., 13) are males and those beginning with 3 or 4 (e.g., 46) are females. Rats were pair-housed in same-sex pairs with separate rooms for each sex in a temperature-controlled colony with a 12:12 hour light/dark cycle (lights on at 700 hours). The colony was located within a facility that was certified by the American Association for Laboratory Animal Care (AALAC). Rats were maintained at 85% of their estimated free-feeding weights by supplemental post-session rat chow. Free-feeding weights were estimated from growth curves provided by Charles River Laboratories. Experimental sessions were conducted daily during the light cycle. Rats were randomly assigned to a Fixed-Delay (FD) or Variable-Delay (VD) pre-exposure group; however, one female rat was assigned to the VD pre-exposure group instead of the FD pre-exposure group due to
experimenter error. Thus, the sample sizes were \( n = 7 \) for the FD pre-exposure group and \( n = 9 \) for the VD pre-exposure group.

**Apparatus**

We used four Coulbourn Instruments Inc. operant conditioning chambers in sound-attenuating boxes. Each chamber measured 29 cm \( \times \) 24 cm \( \times \) 29 cm and was equipped with a houselight and three retractable levers on the right panel. Each chamber was equipped with two pellet receptacles, one above the left lever and one above the right lever, and each pellet receptacle delivered 45-mg grain-based food pellets (Bio-Serv®). Each pellet receptacle was equipped with a stimulus light that illuminated when a food pellet was delivered. In addition, there was a stimulus light above each pellet receptacle and a stimulus light above the center lever.

**Procedure**

Our experimental design was modeled after other studies employing delay pre-exposure procedures (e.g., Renda et al., 2016; Smith et al., 2015; Tosun et al., 2016). Figure 2 shows the order of conditions for this experiment.

**Figure 2**

*Order of Conditions in Experiment 1*

![Diagram](image)

*Note.* Rats first completed initial training and amount-discrimination training. After amount-discrimination training, rats were assigned to either the FD or VD pre-exposure group. Next, each rat completed exposure training after which we conducted a second iteration of amount-discrimination training. Finally, all rats were tested on the increasing-delay delay of gratification (DoG) task.
Initial Training

Rats were first trained to eat food pellets from the left and right receptacles during magazine training. Magazine training was composed of 30 trials, with each trial separated by a variable intertrial interval (ITI) with a mean of 90 s, calculated according to Fleshler and Hoffman’s (1962) constant-probability distribution. Each session began with an ITI, during which the houselight was illuminated. After the ITI, the houselight extinguished and a single food pellet was delivered randomly in either the left or right pellet receptacle according to a 30-item list with each receptacle represented an equal number of times in the list (i.e., 15 left & 15 right). After the pellet was delivered, the houselight illuminated and the ITI began. Magazine training lasted for one session.

After magazine training, we trained rats to lever-press using autoshaping (Brown & Jenkins, 1968; Papini & Brewer, 1994). Sessions of autoshaping were structured the same as magazine training; however, at the start of a trial, either the left or right lever, randomly determined using the 30-item list described above, extended into the chamber and the stimulus light above the lever illuminated. If the rat pressed the lever or 10 s elapsed (whichever occurred first), the lever retracted, the stimulus light above the lever extinguished, and a single food pellet was delivered into the receptacle above the lever. Autoshaping lasted two sessions.

After autoshaping, rats completed one session of chained fixed ratio 1 fixed ratio 1 (FR1-FR1) lever-press training. The session of FR1-FR1 training was composed of 60 trials. At the start of a trial, the center lever extended into the chamber, and the stimulus light above the center lever illuminated. After a rat pressed the center lever, the center lever retracted, the stimulus light above the center lever extinguished, one of the side
levers, randomly determined using a 60-item list (30 left & 30 right), extended into the chamber, and the stimulus light above the extended side lever illuminated. After a rat pressed the extended side lever, that lever retracted, the stimulus light above the lever extinguished, and a single food pellet was delivered in the receptacle above the lever. Following food delivery, the next trial began immediately. After the FR1-FR1 training session, rats were transitioned to amount-discrimination training.

**Amount-Discrimination Training**

After the FR1-FR1 training session, we trained rats to discriminate between a smaller and larger number of food pellets. Sessions were composed of 60 trials, divided into five blocks of 12 trials each and each trial was separated by a compensating ITI that maintained 60 s between the start of each trial. The first two trials in a block were forced-choice trials which exposed rats to both outcomes. At the start of a forced-choice trial, the houselight illuminated, the center lever extended, and the stimulus light above the center lever illuminated. After a rat pressed the center lever (i.e., made a centering response), the center lever retracted, the stimulus light above the center lever extinguished, one of the side levers, randomly determined, extended into the chamber, and the stimulus light above the extended lever illuminated. After a rat pressed the extended side lever (i.e., made a choice response), that lever retracted, the houselight and stimulus light extinguished, and either 1 or 3 food pellets were delivered immediately. During one forced-choice trial, a press on one side lever resulted in 1 food pellet. During the other forced-choice trial, a press on the other side lever resulted in 3 food pellets. The lever-outcome arrangement (e.g., 3-pellet option on left lever) was counterbalanced across rats but remained constant within and across sessions for each rat. In other words, for some
rats, the left lever was always associated with 1 food pellet and the right lever was always associated with 3 food pellets; however, for other rats, that arrangement was reversed.

After the two forced-choice trials, there were 10 free-choice trials. Free-choice trials were structured the same as forced-choice trials; however, after a rat made a centering response, both side levers extended into the chamber and the rat could respond on either lever. During both forced- and free-choice trials, if a rat did not make a centering response or a choice response within 10 s of trial onset or side-lever presentation, respectively, the trial ended and was counted as an omission. If a rat omitted a forced-choice trial, that trial was repeated once. If a rat omitted the repeated forced-choice trial, the session continued as if the rat had responded during that trial. However, if a rat omitted a free-choice trial, that trial was not repeated. These omission-criteria were also used during the increasing-delay delay of gratification task. We chose to repeat each forced-choice trial only once because data from Haynes and Odum (2022) indicate that some rats will selectively and repeatedly omit forced-choice trials in which there is a long delay (e.g., 32 s) to a larger-later reinforcer, thereby stalling the experimental session.

During amount-discrimination training, we conducted a lever reversal to identify and address potential lever biases. Specifically, a rat was exposed to the same lever-outcome arrangement until the larger (3-pellet) option was chosen on at least 80% of trials for two consecutive sessions. After a rat met the 80% choice-criterion, the lever-outcome arrangement was reversed. After a rat met the 80% choice-criterion on the new lever-outcome arrangement, that rat was transitioned to exposure training. We implemented remedial training for two rats that did not meet the 80% choice-criterion
within three sessions. For one rat (VD-24), remedial training occurred during the initial lever-outcome arrangement and for the other rat (VD-43), remedial training occurred after the lever-outcome arrangement was reversed. Remedial training involved two consecutive sessions of all forced-choice trials for the 3-pellet option (Renda et al., 2018). After remedial training, each rat was returned to amount-discrimination training and required no further remedial training.

**Exposure Training**

Exposure training involved pre-exposing rats to parameters of the delay of gratification task prior to testing on that task. The pre-exposure procedure was based on a procedure from a study in which mice were pre-exposed to the parameters (i.e., locations, probabilities, & delays) associated with food delivery from a temporal bisection task (Tosun et al., 2016). In that study, mice were immediately sensitive to the parameters of food delivery upon subsequent testing in the temporal bisection task, indicating that the pre-exposure procedure was successful in producing control by those parameters. Thus, we developed a similar pre-exposure procedure with the goal of obtaining temporal control of behavior according to two different delay progressions with parameters related to the delay of gratification task.

Throughout exposure training, we exposed rats to a smaller-immediate (1-pellet) and larger-later (3-pellet) reinforcer. Similar to amount-discrimination training, sessions were composed of 60 trials and each trial was separated by a 60-s compensating ITI. At the start of a trial, the houselight illuminated, the center lever extended, and the stimulus light above the center lever illuminated. After a rat pressed the center lever, the center lever retracted, the stimulus light above the center lever extinguished, and either the 1-
pellet option was delivered in one receptacle, or the 3-pellet option was delivered in the other receptacle. The side in which the 1- and 3-pellet options were delivered corresponded to the same side in which the rat received the 1- and 3-pellet options at the conclusion of amount-discrimination training. During the delay to the 3-pellet option, the stimulus light above the pellet receptacle flashed on/off every 0.5 s. If a rat did not make a centering response within 10 s of trial onset, the trial ended and was counted as an omission. Next, we describe the delay progressions for each group.

For rats in the Fixed-Delay (FD) pre-exposure group, sessions were structured to expose rats to the same increasing delay progression that would be used in the delay of gratification task. Specifically, sessions were organized into 5 blocks of 12 trials each. For each block, we used a 12-item list to randomly determine whether the smaller-immediate (1-pellet) or larger-later (3-pellet) option would be delivered on a given trial within that block. Each option was delivered an equal number of times within a block as well as throughout each session. Across blocks of trials, the delay to the 3-pellet option increased in the following progression: 0, 4, 8, 16, and 32 s (Haynes & Odum, 2022; Reynolds et al., 2002). Thus, rats in the FD pre-exposure group experienced the same delay progression that would be used in the delay of gratification task.

For rats in the Variable-Delay (VD) pre-exposure group, sessions were structured to expose rats to a delay progression that had the same mean delay as the delay of gratification task; however, unlike the FD pre-exposure group, delays varied from trial to trial. For rats in the VD pre-exposure group, sessions were not organized into blocks of trials. Instead, we used a 60-item list to randomly determine whether the smaller-immediate (1-pellet) or larger-later (3-pellet) option would be delivered on a given trial.
As in the FD pre-exposure group, each outcome was delivered an equal number of times within a session. The delay to the 3-pellet option varied from trial to trial according to a 30-item constant-probability distribution (Fleshler & Hoffman, 1962). The mean of the distribution was 12 s which would be the arithmetic mean delay to the 3-pellet option in the delay of gratification task. Thus, rats in the VD pre-exposure group experienced variable delays that had the same arithmetic mean delay to the 3-pellet option experienced by rats in the FD pre-exposure group.

For both groups of rats, exposure training lasted 20 sessions (Tosun et al., 2016). Immediately after exposure training, rats were returned to amount-discrimination training as described above. After a rat chose the larger (3-pellet) option on at least 80% of trials for two consecutive sessions, the rat was transitioned to the increasing-delay delay of gratification task. Only two rats required more than two sessions on this return to amount-discrimination training (5 sessions for VD-25 & 3 sessions for VD-33B).

**Increasing-Delay Delay of Gratification (DoG) Task**

The increasing-delay DoG task was structured similar to amount-discrimination training; however, the delay to the larger (3-pellet) option increased across blocks of trials. The delay progression during the task was the same progression experienced by rats in the FD pre-exposure group: 0, 4, 8, 16, and 32 s (Haynes & Odum, 2022; Reynolds et al., 2002). During the delay, the stimulus light above the pellet receptacle flashed on/off every 0.5 s as in exposure training. This task was similar to other increasing-delay intertemporal choice tasks (e.g., Evenden & Ryan, 1996); however, after a rat chose the 3-pellet option, the rat could reverse its preference during the delay to that option. That is, if a rat initially chose the 3-pellet option, that lever retracted, leaving the
lever for the smaller (1-pellet) option available during the delay. If the rat responded on the lever for the 1-pellet option during the delay (i.e., a defection response), that lever retracted, 1 food pellet was delivered immediately, and the trial ended. If the rat did not respond on the lever for the 1-pellet option during the delay, all levers retracted, 3 food pellets were delivered, and the trial ended. If the rat initially chose the 1-pellet option, all levers retracted, 1 food pellet was delivered immediately, and the trial ended. This condition lasted for 12 sessions.

**Data Analysis**

We used mixed effects modeling to analyze data from both conditions. Models were fit in R using the lme4 package and our data set and code are available on the Open Science Framework (OSF, https://osf.io/kuhxs/?view_only=edfd0e4330c461588069573a1ae5057; Bates et al., 2015; R Core Team, 2019). Mixed effects models are regression models appropriate for analyzing repeated measures and are well-suited for handling missing data (i.e., omissions) and unbalanced datasets (i.e., unequal number of subjects between groups; Hox et al., 2017). For each model, we first fit an initial, random-intercept model with all predictors and their interactions (i.e., a full factorial). After fitting the random-intercept model, we examined whether the inclusion of random slope effects significantly improved model fit. Random slope effects allow for the effect of a predictor (e.g., change over time with the session predictor) to vary for each subject in the model, allowing for subject-to-subject variability in the effect of that predictor. We added random slope effects one at a time and retained that effect if it significantly improved model fit according to a likelihood ratio test (Hox et al., 2017). After including random slope
effects, we evaluated the significance of predictors with Wald tests using the car package (Fox & Weisberg, 2019). Follow-up comparisons were conducted using the emmeans package in R with false-discovery rate (FDR) corrections (Benjamini & Hochberg, 1995; Lenth, 2021). We used FDR corrections to control our Type I error rate while at the same time avoiding Type II errors associated with particularly strict correction procedures (e.g., Bonferroni; Noble, 2009). Three rats (FD-46, VD-43, & VD-43B) were excluded from the analyses described below because these rats chose the larger option on fewer than 80% of trials in the 0-s delay-block (i.e., failed to discriminate amount; Haynes & Odum, 2022; Renda & Madden, 2016) on 6 or more (i.e., ≥ 50%) sessions of the increasing-delay DoG task. Next, we describe specific details of each model.

**Exposure Training**

For exposure training, we examined center response latencies as an indicator of sensitivity to delay because prior research shows that response latencies increase as the delay to a larger-later reinforcer increases in intertemporal choice tasks for rats (e.g., Stein et al., 2015; Wilhelm & Mitchell, 2009). We calculated center response latencies as the time between the start of a trial and a centering response. Trials were organized into consecutive 12-trial blocks. For rats in the FD pre-exposure group, these blocks correspond with the delays in the increasing delay progression, whereas for rats in the VD pre-exposure group, these blocks correspond with delays that varied from trial to trial and not to the specific delays in the increasing delay progression. We fit a linear mixed

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12 For two of these rats, we conducted a return to amount-discrimination training and after meeting amount-discrimination criteria, they were transitioned back to the DoG task. These rats discriminated amount after the return to the DoG task; however, because they did not discriminate amount on the majority of DoG sessions, we chose to remove data from these rats. The results were not meaningfully different with the inclusion of these rats and the data are available on OSF for interested readers.
model (LMM) with latency as the dependent variable and fixed effects of block (categorical), group (categorical), session (continuous), and their two- and three-way interactions. We log-transformed center response latencies because this improved normality and homoskedasticity. In addition, we standardized sessions on a scale from 0 (session 1) to 1 (session 20) and then centered each session by subtracting .5 from the standardized session.

**Increasing-Delay DoG Task**

**Initial vs. Final Choice.** We examined choice of the larger-later (3-pellet) option within- and between-groups using an approach like that of Haynes and Odum (2022). Only sessions in which a rat chose the larger (3-pellet) option on more than 80% of trials in the 0-s delay-block (i.e., discriminated amount) were included in this analysis. We organized choice data from each trial for each rat in terms of initial and final choices for the 3-pellet option (cf. Forzano et al., 2011). An initial choice refers to the outcome a rat first chose, regardless of whether the rat made a defection response. A final choice refers to the outcome a rat ultimately received, considering whether the rat made a defection response. For example, if a rat initially chose the 3-pellet option but defected on that choice, that trial was coded as an initial choice for the 3-pellet option but as a final choice for the 1-pellet option. Importantly, differences between initial and final choices for the 3-pellet option indicate the degree to which rats defected on their choice of that option.

Because the dependent variable was binary (i.e., 1-pellet option vs. 3-pellet option), we fit a generalized linear mixed model (GLMM) with a logit link (Young, 2018). The GLMM included fixed effects of delay (continuous), choice type (categorical: initial vs. final), session (continuous), group (categorical), and their two-, three-, and
four-way interactions. We used effect coding for the choice type variable (initial choice = +1 & final choice = -1; cf. Haynes & Odum, 2022). In addition, we log-transformed the delays because this improved model fit according to Akaike Information Criteria (Burnham & Anderson, 2004; Young et al., 2012; Young, 2018). We added a constant of 1 to each delay to avoid log-transforming zero. Log-transformed delays were standardized and centered by dividing each delay by the longest log-transformed delay (32 s) and subtracting .5 from each standardized delay. Similarly, we standardized sessions on a scale from 0 (session 1) to 1 (session 12) and centered each session by subtracting .5 from the standardized session.

To visualize changes in choice across time, we calculated area under the curve (AUC) as a more global measure of choice (Myerson et al., 2001). Area under the curve was calculated by summing the area under plotted initial and final choice proportions at each delay, using the following equation:

$$\sum (x_2 - x_1) \left[ \frac{(y_1 + y_2)}{2} \right]$$

where $x_2$ and $x_1$ are adjacent delays and $y_1$ and $y_2$ are the adjacent proportions for those delays (Myerson et al., 2001). Area under the curve ranges from 0 to 1 such that higher values correspond to more choices for the 3-pellet option. In addition, we log-transformed the delays to account for the disproportionate influence that longer delays have in the calculation of AUC (Borges et al., 2016).

**Supplemental Analysis**

In addition to analyzing choice data from the DoG task, we conducted analyses on defection latencies and defection counts from the increasing-delay DoG task. For brevity, we omit the results of these analyses and their discussion here but provide them in the
supplemental file on OSF with the data. We chose to omit these analyses and their discussion because we were primarily interested in the effect of pre-exposure training as it relates to choice in the increasing-delay DoG task.

**Results**

**Exposure Training**

During exposure training, rats in both groups showed increases in center response latencies across blocks of trials; however, this increase across blocks of trials was greater among rats in the FD pre-exposure group. To illustrate, Figure 3 shows model-predicted center response latencies as a function of block for rats in both groups, collapsed across sessions. We collapsed across sessions to focus on the group × block interaction which was of primary interest in this analysis (see below). We display center response latencies as a function of session in the supplemental file on OSF. Model-predictions in Figure 3 were generated from the final LMM fit to the log-transformed center response latencies (see Table 1). This model included a random slope effect for session because doing so significantly improved model fit, $\chi^2(2) = 634.34, p < .001$, allowing for changes in center response latencies across time to vary for each rat in the model. Overall, the model revealed that center response latencies were, on average, similar between groups according to no main effect of group, $\chi^2(1) = 0.36, p = .55$; however, we did find a significant block × group interaction, $\chi^2(4) = 133.79, p < .001$. To clarify the nature of this interaction, we compared the linear increase in center response latencies across blocks of trials between the FD and VD pre-exposure groups. This comparison is important because we also found a significant main effect of block, $\chi^2(4) = 492.12, p < .001$, suggesting that center response latencies tended to increase across blocks of trials.
for rats in both groups. Thus, we sought to determine whether this increase across blocks of trials was greater among rats in the FD pre-exposure group. This post-hoc comparison was significant, $z = -11.41, p < .001$, indicating that center response latencies increased across blocks of trials to a greater degree among rats in the FD pre-exposure group than among rats in the VD pre-exposure group.

**Figure 3**

*Center Response Latencies During Exposure Training (Experiment 1)*

*Note.* Model-predicted center response latencies as a function of block for the FD and VD pre-exposure groups during exposure training. Predicted values at the group (connected datapoints) and individual-subject (unconnected datapoints) levels were generated from the final LMM fit to the log-transformed center response latencies during this phase. Note that the y-axis is logarithmic. Error bars represent 95% confidence intervals and groups are offset on the x-axis so that data from both groups are visible.

**Table 1**

*Results from the final LMM fit to log-transformed center response latencies from exposure training (Experiment 1)*

<table>
<thead>
<tr>
<th>Fixed Effects</th>
<th>$\chi^2$</th>
<th>df</th>
<th>$p$</th>
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<td>Intercept</td>
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<td>&lt;.001</td>
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<tr>
<td>Session</td>
<td>12.93</td>
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<td>Block</td>
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<tr>
<td>Block × Group</td>
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<td>4</td>
<td>&lt;.001</td>
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<tr>
<td>Session × Block × Group</td>
<td>6.19</td>
<td>4</td>
<td>.19</td>
</tr>
</tbody>
</table>
In addition, center response latencies tended to decrease across sessions of exposure training. This effect was captured in the model by a significant main effect of session, $\chi^2(1) = 12.93, p < .001$. The decrease in center response latencies across sessions occurred primarily among rats in the FD pre-exposure group (see Figure S1 in the supplemental file), but we did not find a significant session $\times$ group interaction, $\chi^2(1) = 2.01, p = .16$, which would have captured this finding. In addition, we did not find a significant session $\times$ block interaction, $\chi^2(4) = 0.18, p > .99$, indicating that center response latencies did not differentially decrease at a specific delay. Finally, we did not find a significant session $\times$ block $\times$ group interaction, $\chi^2(4) = 6.19, p = .19$. The lack of this three-way interaction indicates that sensitivity to delay, as indicated by increases in center response latencies across blocks of trials, did not emerge over time among rats in the FD pre-exposure group, but was present early in training.

**Increasing-Delay DoG Task**

**Initial vs. Final Choice**

During the increasing-delay DoG task, initial and final choices for the larger-later (3-pellet) option tended to decrease as the delay to that option increased; however, for many rats, initial choices were less sensitive to delay than final choices. To illustrate, Figure 4 shows initial and final choice proportions as a function of delay for rats in the FD and VD pre-exposure groups, respectively, during the first and last 3 sessions of the task.
DoG task. As the left panels show, initial choice proportions for the 3-pellet option were close to 1.00 across many delays for several rats, whereas final choice proportions tended to decrease systematically as the delay to the 3-pellet option increased during these initial sessions. Across sessions, however, initial choice proportions tended to decrease as the delay to the 3-pellet option increased (see right panels in Figure 4). Figure 5 also shows these changes across time in terms of AUC for each group of rats. Next, we describe the results from the final GLMM which characterizes these effects.

Figure 4
Choice Data from the Increasing-Delay DoG Task (Experiment 1)

Note. Proportion of initial and final choices for the larger-later (3-pellet) option as a function of delay during the first and last 3 sessions (columns) of the DoG task for the Fixed-Delay (FD) and Variable-Delay (VD) pre-exposure groups (rows). Group medians are presented as darker datapaths and individual-subject data are presented as lighter datapoints. Data have been jittered on the x-axis so that all are visible.
Figure 5

AUC During Increasing-Delay DoG Task (Experiment 1)

Note. Initial and final choice AUC as a function of session for rats in the Fixed-Delay (FD) and Variable-Delay (VD) pre-exposure groups (rows). Individual-subject data are presented as lighter, unconnected data points. Group medians are presented as darker, connected data points.

As described above, we built the final GLMM by fitting a full factorial random-intercept model and examined whether the inclusion of random slope effects significantly improved model fit. First, we included a random slope effect for delay because doing so significantly improved model fit, $\chi^2(2) = 563.76, p < 0.001$, allowing sensitivity to delay to vary for each rat. Next, inclusion of a random slope effect for choice type significantly improved model fit, $\chi^2(3) = 1148.50, p < .001$; therefore, we retained this effect in the model, allowing for the difference between initial and final choices to vary for each rat. Finally, we found that including a random slope effect for session significantly improved model fit, $\chi^2(4) = 172.29, p < .001$; therefore, this effect was retained in the final model, allowing for changes in choice (both initial & final) across sessions to vary for each rat.
After including these random slope effects, we evaluated the significance of the predictors using this final model.

Figure 6A shows the predicted probability of an initial and final choice for the larger-later (3-pellet) option as a function of delay during the first and last 3 sessions of the increasing-delay DoG task for both groups of rats. Predicted probabilities were generated from the final GLMM fit to the choice data (see Table 2). This model showed that the likelihood of an initial choice for the 3-pellet option was higher than the likelihood of a final choice for that option according to a significant main effect of choice type, $\chi^2(1) = 13.77, p < .001$. In addition, we found that initial choices for the 3-pellet option were less sensitive to delay than final choices for that option. Thus, although the model revealed a significant main effect of delay, $\chi^2(1) = 106.19, p < .001$, we also found a significant delay $\times$ choice type interaction, $\chi^2(1) = 161.50, p < .001$. The model also showed that both initial and final choices for the 3-pellet option decreased across sessions according to a significant main effect of session, $\chi^2(1) = 23.84, p < .001$; however, as Figure 6A shows, these decreases were greatest at longer delays for initial choices, and these decreases differed between groups. This latter finding is best characterized in the model by a significant delay $\times$ group $\times$ session $\times$ choice type interaction, $\chi^2(1) = 10.71, p = .001$. Other significant two- and three-way interactions were detected (see Table 2); however, we will hereafter focus on follow-up comparisons for the four-way interaction because this best characterizes these effects.
Figure 6
Results of GLMM on Choice Data from Increasing-Delay DoG Task (Experiment 1)

Note. Top panels (A): Predicted probabilities of an initial and final choice for the larger-later (3-pellet) option as a function of delay during the first and last 3 sessions of the DoG task for each group of rats (rows), generated from the final GLMM. Error bands represent 95% confidence intervals. Bottom panels (B): Estimated differences between the probability of an initial vs. final choice of the 3-pellet option as a function of delay for each group of rats, generated from the final GLMM. Upper error bars represent upper limits for the 95% confidence intervals. Note that the delays are presented ordinally on these panels.

Table 2
Results from the final GLMM on choice data from the increasing-delay DoG task (Experiment 1)

<table>
<thead>
<tr>
<th>Fixed Effects</th>
<th>$\chi^2$</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.91</td>
<td>1</td>
<td>.09</td>
</tr>
<tr>
<td>Log Delay</td>
<td>106.19</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Group</td>
<td>1.95</td>
<td>1</td>
<td>.16</td>
</tr>
<tr>
<td>Session</td>
<td>23.84</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Choice Type</td>
<td>13.77</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Log Delay × Group</td>
<td>1.13</td>
<td>1</td>
<td>.29</td>
</tr>
<tr>
<td>Log Delay × Session</td>
<td>31.23</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Group × Session</td>
<td>0.53</td>
<td>1</td>
<td>.47</td>
</tr>
<tr>
<td>Log Delay × Choice Type</td>
<td>161.50</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Group × Choice Type</td>
<td>1.95</td>
<td>1</td>
<td>.16</td>
</tr>
<tr>
<td>Session × Choice Type</td>
<td>0.22</td>
<td>1</td>
<td>.64</td>
</tr>
</tbody>
</table>
To explore the four-way interaction, we conducted post-hoc comparisons to examine within- and between-group differences in defection responses during the increasing-delay DoG task. To do this, we first compared the probability of an initial choice for the larger-later (3-pellet) option against the probability of a final choice for that option at the 4-, 8-, 16-, and 32-s delays within each group of rats during the first and last 3 sessions of the DoG task. The larger the difference between these probabilities, the more rats defected. To illustrate, Figure 6B shows the estimated difference in the probability of an initial vs. final choice of the 3-pellet option, described further below.

Both groups frequently defected at the beginning of the DoG task but showed fewer defections across sessions (Figure 6B). For both groups, the probability of an initial choice for the larger-later (3-pellet) option was significantly higher than a final choice for that option at each delay during the first 3 sessions of the task (all \(p < .05\)), indicating that rats across both groups frequently defected at the beginning of the DoG task. During the last 3 sessions of the DoG task, rats in the FD pre-exposure group continued to frequently defect at the 4- and 8-s delays as indicated by significant differences between initial and final choice probabilities at these delays during the last 3 sessions (all \(p < .01\)).
.001). At the 16-s delay, the probability of an initial choice for the 3-pellet option was only significantly higher than a final choice for that option during sessions 10 and 11 for rats in the FD pre-exposure group (both $p < .05$), and at the 32-s delay, these probabilities were not significantly different during any of the last 3 sessions of the task for this group. In contrast, rats in the VD pre-exposure group rarely defected during the last 3 sessions of the DoG task, as indicated by no significant differences between initial and final choice probabilities at any delay during the last 3 sessions of the task (all $p > .05$). Thus, between the first and last 3 sessions of the increasing-delay DoG task, rats across both groups showed fewer defections across time with rats in the VD pre-exposure group showing fewer defections across a wider range of delays.

Next, we examined between-group differences in defection responses. To do this, we calculated within-group differences in the probability of an initial vs. final choice for the larger-later (3-pellet) option, as described above, and then compared these within-group differences between the FD and VD pre-exposure groups at each delay during the first and last 3 sessions of the DoG task. This analysis showed no significant differences between the FD and VD pre-exposure groups at any delay during the first and last 3 sessions of the DoG task (all $p > .05$). Thus, although rats in the VD pre-exposure group tended to make fewer defection responses than rats in the FD pre-exposure group (see Figure 6B), the groups did not significantly differ with respect to how frequently they defected.

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13 As a similar but more direct comparison, we also conducted an LMM with number of defection responses in each block of trials as the dependent variable with fixed effects of delay-block, group, session, and their interactions (see supplemental file). This analysis revealed qualitatively similar results; therefore, we only present the GLMM on choice data for brevity.
Discussion

Our results show that rats pre-exposed to either fixed- or variable-delays frequently defect on their choice of a larger-later reinforcer in a delay of gratification task. Across rats in the FD and VD pre-exposure groups, initial choices for the larger-later (3-pellet) option were high and insensitive to the increasing delay progression, whereas final choices for the 3-pellet option were lower and sensitive to the delay progression. That is, rats initially chose the 3-pellet option frequently, even at long delays (e.g., the 32-s delay) but subsequently defected on many of those choices. Across sessions, however, rats across both groups tended to defect less as initial choices became more sensitive to the increasing delay progression (i.e., rats began choosing the larger option less at longer delays). Although there were no overall between-group differences in defections, we found that rats in the VD pre-exposure group tended to show fewer defection responses than rats in the FD pre-exposure group by the end of the task. Next, we describe the potential implications of these results.

Contrary to our prediction, pre-exposure to a delay progression that was identical to that of a delay of gratification task did not reduce defection responses in that task. We predicted that rats in the FD pre-exposure group would rarely defect on their choice of the larger (3-pellet) option because the delay progressions for that option were identical between exposure training and the delay of gratification task. We instead found that this group of rats frequently defected on their choice of the 3-pellet option and did so more, although not statistically more, than rats in the VD pre-exposure group. These findings are inconsistent with predictions by Rachlin (2000) and from McGuire and Kable’s (2013) Normative Perspective; however, it is possible that 20 sessions of exposure
training were insufficient to facilitate the development of temporal control. We chose 20 sessions based on the number of sessions employed by Tosun et al. (2016) using a similar procedure with mice. Although rats may require more pre-exposure training, research using foraging tasks show that temporal control of behavior can be obtained with a similar amount of training in rats (25 sessions; Duin et al., 2021). Furthermore, rats in the FD pre-exposure group were sensitive to the increasing delay progression during exposure training because center response latencies increased across blocks of trials; however, this finding can only be interpreted as indicating sensitivity to delay and not the development of temporal control. Specifically, this pattern of behavior occurred early in training and did not emerge over time as might be expected with the development of temporal control. Therefore, in Experiment 2, we systematically replicated aspects of this experiment and a previous experiment conducted by Haynes and Odum (2022, Experiment 2) so that we could verify whether temporal control develops during exposure training.

Consistent with our prediction, we found that pre-exposure to a variable delay progression was initially associated with frequent defections in a delay of gratification task; however, contrary to our prediction, this pre-exposure training was associated with fewer defection responses over time. That is, we predicted that rats in the VD pre-exposure group would frequently defect on their choice of the larger (3-pellet) option because the delay progressions were different between exposure training and the delay of gratification task. Although this group frequently defected initially, they showed fewer defection responses across a wider range of delays than rats in the FD pre-exposure group by the end of the task, a finding that is opposite of what we predicted.
Following the completion of the study, we became aware of an alternative hypothesis in which rats in the VD pre-exposure group would be expected to rarely defect on their choice of the larger-later (3-pellet) option because of the properties of the variable delay progression during exposure training (G. J. Madden, personal communication). Specifically, variable delay progressions calculated according to a Fleshler and Hoffman (1962) distribution have a constant probability of food delivery per unit of time. Therefore, if rats in the VD pre-exposure group generalized temporal control from exposure training to the DoG task, these rats may have been more likely to wait for the 3-pellet option after it was chosen because the expected delay to the larger reinforcer would be constant. The finding that rats in the VD pre-exposure group showed fewer defection responses across time provides some support for this hypothesis; however, it should be noted that the decrease in defections occurred because rats began choosing the larger reinforcer less, rather than by waiting more frequently. Thus, the reduction in defection responses as a function of variable-delay pre-exposure training appears to reflect an increased sensitivity to delay among initial choices and not increased waiting as may be expected by this hypothesis.

**Experiment 2**

In Experiment 2, we focused on exploring predictions from Rachlin (2000) and McGuire and Kable (2013) as they relate to the findings from the FD pre-exposure group. Exploring these predictions was important because we interpreted the findings by Haynes and Odum (2022) as consistent with their perspectives regarding the role of temporal expectations in delay of gratification. Specifically, Haynes and Odum found that rats with prior experience on a delay of gratification task and on an intertemporal choice task
rarely defected on their choices of a larger-later sucrose reinforcer. Those findings were consistent with Rachlin and McGuire and Kable’s perspectives because rats may have learned the delays to the larger option from those prior experiences and thus temporal expectations should have been stable during the delay to the larger option after it was chosen. Given that our findings from Experiment 1 could be interpreted to represent evidence against these perspectives, a second goal of Experiment 2 was to examine a potentially important procedural difference that could explain the discrepant findings between Experiment 1 of this study and of Haynes and Odum’s study.

In this experiment, we systematically replicated aspects of Experiment 1 and of Haynes and Odum’s (2022) Experiment 2 to more rigorously test whether temporal expectations influence preference reversals in a delay of gratification task. In Haynes and Odum’s study, rats completed an intertemporal choice task with the same delay progression as a delay of gratification task; when those rats were subsequently transitioned to the delay of gratification task, those rats rarely defected. Haynes and Odum attributed their findings to temporal learning that may have occurred during the intertemporal choice task. In the present experiment, two groups of rats were exposed to the delays associated with a larger-later reinforcer. For one group (hereafter referred to as the ITC group), rats were exposed to delays as a function of their choices in an intertemporal choice task based on the task used by Haynes and Odum. The number of sessions until stability on the intertemporal choice task was used to determine the duration of fixed-delay pre-exposure training for the other group of rats (hereafter referred to as the Yoked-Delay group) that were exposed to delays. This group of rats was exposed to delays not as a function of their choices using a task similar to that of the
Fixed-Delay pre-exposure group in Experiment 1. For both of these groups (i.e., the ITC & the Yoked-Delay groups), we equated the amount of within-session exposure to the larger-later reinforcer by yoking the number of times that rats in the Yoked-Delay group experienced the larger-later option to the number times rats in the ITC group chose the larger-later option. Finally, we used response-initiated fixed-interval schedules (Shull, 1970) instead of response-initiated fixed-time schedules (cf. Experiment 1; Haynes & Odum, 2022, Experiment 2) during the intertemporal choice task and the fixed-delay pre-exposure training procedure so that we could measure temporal control during exposure training by having a measure of lever pressing during the interval (Smith et al., 2015).

In addition to the two groups described above, we also included a control group of rats (hereafter referred to as the Yoked-Amount group) who were not exposed to delays during exposure training. Rats in this group completed a form of training similar to that of the Yoked-Delay group; however, rats in the Yoked-Amount group received the larger option immediately during exposure training (cf. immediacy-exposed rats in delay-exposure training; Renda & Madden, 2016). All other aspects of training for the Yoked-Amount group were the same as the Yoked-Delay group; therefore, all three groups experienced the same reinforcers during exposure training, but groups differed with respect to whether and how they experienced delays to the larger reinforcer. After completing exposure training, all rats experienced the increasing-delay delay of gratification task.

Based on predictions from Rachlin (2000) and McGuire and Kable (2013), we expected defection responses in the delay of gratification task to be lower among rats in the ITC and Yoked-Delay groups than among rats in the Yoked-Amount (control) group.
Specifically, we predicted rats in the ITC and Yoked-Delay groups would rarely defect because they would have had the opportunity to learn the delays to the larger option during exposure training. Thus, if rats in the ITC and Yoked-Delay groups generalized temporal control from exposure training to the delay of gratification task, we predicted that temporal expectations would be stable, and thus preference to be stable, during the delay to the larger option after it was chosen in the delay of gratification task, resulting in fewer defections. In contrast, we expected rats in the Yoked-Amount group to frequently defect because they did not have the opportunity to learn the delays to the larger option during exposure training. Thus, if preference reversals result from changes in temporal expectations, we predicted that these rats would frequently defect because temporal expectations, and thus preference, would be more likely to shift during the delay to the larger option after it was chosen in the delay of gratification task, resulting in more defections.

The predictions described above were generated under the assumption that in Experiment 1, rats in the FD pre-exposure group frequently defected because we did not obtain temporal control of behavior during exposure training. In addition, however, these predictions also assume that the intertemporal choice task used by Haynes and Odum (2022, Experiment 2) led to fewer defections in the delay of gratification task because they had obtained temporal control of behavior during the intertemporal choice task. In the present experiment, we obtained measures of temporal control for rats in the ITC and Yoked-Delay groups, and we were able to compare temporal control between these two groups prior to testing on the delay of gratification task. If obtaining temporal control of behavior during exposure training leads to fewer defection responses in the subsequent
delay of gratification task, these groups should not differ in terms of defections during the delay of gratification task. If, however, other aspects of the intertemporal choice task cause fewer defection responses in the delay of gratification task, then we should observe more defections among rats in the Yoked-Delay group than among rats in the ITC group.

If rats in the Yoked-Delay group defect more frequently than rats in the ITC group during the delay of gratification task, this could indicate that differences between how outcomes are obtained during exposure training influences preference reversals in a delay of gratification task. Specifically, rats in the ITC group will have experienced the outcomes during exposure training as a function of their choices, whereas rats in the Yoked-Delay group will have experienced those outcomes without choosing them. Similarly, rats in Haynes and Odum’s (2022, Experiment 2) study experienced the outcomes during the intertemporal choice task as a function of their choices whereas rats in Experiment 1 of the present study did not experience the outcomes during exposure training as a function of their choices. Prior research indicates that outcomes produced as a function of one’s choices influence future behavior differently than outcomes produced not as a function of one’s choices (Coricelli et al., 2005; Twining et al., 2009); thus, it is possible that this procedural difference could explain why our pre-exposure procedure was ineffective during Experiment 1. In sum, the goal of the present experiment was to more rigorously test predictions from Rachlin (2000) and McGuire and Kable’s (2013) Normative Perspective and at the same time, examine the effect of a procedural variable

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14 This procedural difference could be related research demonstrating that ‘experienced regret’ and ‘experienced disappointment’ influence decision-making in distinct ways. This discussion is beyond the scope of the present study; however, interested readers should refer to Zeelenbeg and Pieters (2007) for a thorough discussion of the differences between regret and disappointment as well as studies by McCormack et al. (2019; regret in intertemporal choices with children), Steiner and Redish (2014; regret in rats), and Sweis et al. (2018; regret in mice).
that could explain why pre-exposure training in Experiment 1 was ineffective in reducing defections.

**Method**

**Subjects**

All procedures were approved prior to the beginning of the experiment by the university’s Institutional Animal Care and Use Committee (IACUC Protocol 12262). We used 24 experimentally naïve Wistar rats (12 males & 12 females; see justification of sample size in Data Analysis) obtained from Charles River Laboratories, aged 53 days upon arrival. Rats were given seven days to acclimate to the colony room prior to beginning the experiment; thus, rats were 60 days of age at the start of the experiment. The housing conditions and feeding regimen were the same as in Experiment 1. In addition, experimental sessions were conducted daily during the light cycle at approximately the same times each day.

**Apparatus**

We used the same chambers as in Experiment 1.

**Procedure**

Figure 7 shows the order of conditions for this experiment.

**Figure 7**
*Order of Conditions in Experiment 2*

*Note.* First, rats completed initial training and amount-discrimination training I. After amount-discrimination training I, rats were assigned to one of three groups using block
randomization. Next, each rat completed exposure training after which we conducted a second iteration of amount-discrimination training (II). After amount-discrimination training II, all rats were tested on the increasing-delay delay of gratification (DoG) task.

**Initial Training**

Initial training was the same as that described in Experiment 1.

**Amount-Discrimination Training I**

Amount-discrimination training I was similar to that of Experiment 1; however, rats were required to press the choice lever twice to receive the smaller and larger reinforcers: one press to choose the reinforcer and one press to collect the reinforcer. This modification was made so that amount-discrimination training I had a similar trial-structure as exposure training (described below). All other aspects of amount-discrimination training I were the same as in Experiment 1 (e.g., lever-reversal and center and choice response omission criteria). After a rat completed amount-discrimination training I, that rat remained idle (i.e., did not complete experimental sessions) until all other rats completed amount-discrimination training I. Once all rats completed amount-discrimination training I, rats were matched into blocks of three rats according to the length of time taken to complete initial and amount-discrimination training. Within each block, we randomly assigned rats to the ITC ($n = 8$), Yoked-Delay ($n = 8$), and Yoked-Amount (control) groups ($n = 8$) with the constraint that 4 males and 4 females were assigned to each group. Following group-assignment, all rats completed an additional session of amount-discrimination training prior to beginning exposure training. We included this additional session of amount-discrimination training to detect any changes in amount-discrimination among rats that were idle. All rats met the 80% choice-criterion
during this additional session and were thus transitioned to exposure training.

**Exposure Training**

**ITC Group.** Rats in this group completed an increasing-delay intertemporal choice (ITC) task in which rats chose between a smaller-immediate (1-pellet) and a larger-later (3-pellet) food reinforcer. This task was based on that used by Haynes and Odum (2022, Experiment 2), but with a procedural difference that allowed us to measure temporal control (see below). Sessions were structured the same as in amount-discrimination training I; however, the delay to the 3-pellet option increased across blocks of trials in the following progression: 0, 4, 8, 16, and 32 s. During the delay, the stimulus light above the lever flashed on/off every 0.5 s. A rat initiated the delay to the 3-pellet option with the initial choice response and received that option upon the first response after the delay elapsed (i.e., to collect the 3-pellet option). This is a response-initiated fixed-interval (FI) schedule (Shull, 1970) which has been previously used to obtain measures of temporal control in intertemporal choice tasks for rats (e.g., Smith et al., 2015).

Rats finished the increasing-delay ITC task based on the behavioral stability and fixed-time criteria used by Haynes and Odum (2022; Perone, 1991). Behavioral stability was assessed according to the proportion of choices for the larger-later (3-pellet) option. After a rat completed a minimum of 30 sessions, behavior was considered stable if, for each delay-block, the average choice proportion from the last three sessions and the previous three sessions did not differ from the respective combined six-session average by more than 10%. After a rat met behavioral stability, the rat continued the increasing-delay ITC task until all other rats met behavioral stability. Sessions continued until all
rats had met behavioral stability or until 60 daily sessions, whichever occurred first (Haynes & Odum, 2022). Note, however, that the 60-session fixed-time criterion was not required for any rat. Once all rats met behavioral stability, we compared measures of temporal control between rats in the ITC group and rats in the Yoked-Delay group (see Data Analysis). Rats did not differ with respect to measures of temporal control at this point (see Results); therefore, we transitioned all rats to amount-discrimination training II.

**Yoked-Delay Group.** Rats in this group completed a form of exposure training characterized by forced-choice trials that were yoked to the choices made by rats in the ITC group. Specifically, a rat in the Yoked-Delay group received forced-choice trials for the same outcomes chosen by their matched ITC rat. As in the intertemporal choice task, sessions were composed of 5 blocks of 12 trials each. The first two trials of each block were the same forced-choice trial structure described above. Following these first two trials, the next 10 trials were forced-choice trials for either the smaller-immediate (1-pellet) or larger-later (3-pellet) option according to a probability derived from the proportion of choices for those options by the matched ITC rat during free-choice trials in the intertemporal choice task (cf. Galizio et al., 2018). Probabilities were set on a block-by-block and session-by-session basis. For example, if a rat in the ITC group chose the 3-pellet option on 4 of 10 trials within the 8-s delay-block during one session, the matched Yoked-Delay rat had a 40% probability of a forced-choice trial for the 3-pellet option with an 8-s delay on each trial within that delay-block during that session. Experimental sessions for rats in the Yoked-Delay and Yoked-Amount (see below) groups were conducted after rats in the ITC group on the same day so that we could obtain these
probabilities on a session-by-session basis. All other aspects of exposure training for the Yoked-Delay group were the same as in the intertemporal choice task (e.g., 60-s compensating ITI). Finally, rats in the Yoked-Delay group completed the same number of sessions as rats in the ITC group.

**Yoked-Amount (Control) Group.** Rats in this group also completed a form of exposure training composed of forced-choice trials yoked to the choices made by rats in the ITC group. Unlike rats in the Yoked-Delay group, however, rats in the Yoked-Amount group received the 3-pellet option immediately across all blocks of trials (cf. immediacy-exposed rats in delay-exposure training; Renda & Madden, 2016). All other aspects of training for this group were the same as that of the Yoked-Delay group.

**Amount-Discrimination Training II**

After completing exposure training, all rats were returned to amount-discrimination training; however, we used the same procedure described in Experiment 1 which differed from amount-discrimination training I in that there was no collection response. That is, rats only had to press the lever once for each outcome to be delivered. This change was designed to make the procedure for amount-discrimination training II more similar to the procedure for the increasing-delay delay of gratification (DoG) task. After a rat chose the 3-pellet option on 80% or more trials for two consecutive sessions, that rat was transitioned to the increasing-delay DoG task. Note, we did not conduct a lever reversal as in amount-discrimination training I (cf. Experiment 1).

**Increasing-Delay Delay of Gratification (DoG) Task**

This task was identical to that described in Experiment 1 which had the same session-structure as amount-discrimination training II. Within each session, delays to the
larger (3-pellet) option increased across blocks of trials using the same progression that was used during exposure training for rats in the ITC and Yoked-Delay groups: 0, 4, 8, 16, and 32 s. In addition, we used the same delay-signaling stimuli (i.e., flash) used for rats in the ITC and Yoked-Delay groups during exposure training. As in amount-discrimination training II, rats were not required to make a collection response to obtain either outcome. Removing the collection response essentially changed the response-initiated FI schedules to response-initiated fixed-time (FT) schedules. We used FT schedules instead of FI schedules because FI schedules have been shown to reduce switching between choice alternatives in an intertemporal choice task with pigeons (Siegel & Rachlin, 1995). If FI schedules also reduce switching responses (i.e., defection responses) in a delay of gratification task, this could have decreased our expected effect size. Rats completed 30 sessions of the increasing-delay DoG task. If a rat failed to discriminate amount on a given session (i.e., did not choose the 3-pellet option on at least 80% of trials in the 0-s delay-block), that session was not included in the 30-session fixed-time criterion for this condition and the rat completed additional sessions until the fixed-time criterion was met (cf. Haynes & Odum, 2022, Experiment 2).

**Data Analysis**

We used similar mixed effects modeling approaches described in Experiment 1. For each model, we standardized sessions individually for each rat by dividing each session number for a rat by the highest session number completed during that condition (cf. Haynes & Odum, 2022). After standardizing sessions on a scale from 0 (first session) to 1 (final session), we centered each session by subtracting .5 from the standardized

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15 That is, our effect sizes were based on findings using FT schedules (Haynes & Odum, 2022).
session. For analyses of choice data, we only included sessions in which a rat chose the larger-later (3-pellet) option on at least 80% trials in the 0-s delay-block (i.e., showed amount-discrimination). Finally, we conducted follow-up comparisons using the emmeans package in R with FDR corrections as in Experiment 1 (Lenth, 2021). All data and code are available on OSF (https://osf.io/kuhxs/?view_only=edfde0e4330c461588069573a1ae5057).

**Exposure Training**

**Assessment of Temporal Control.** As described above, we compared measures of temporal control between rats in the ITC and Yoked-Delay groups to determine whether rats in both groups showed similar levels of temporal control by the end of exposure training. To do this, we first calculated index of curvature (Fry et al., 1960) at each delay for rats in the ITC and Yoked-Delay groups using FI trials from each session of exposure training. Index of curvature is a measure of temporal control on FI schedules that summarizes the distribution of responses across time in the interval. We calculated index of curvature by dividing each trial into eight equally spaced bins, summing the number of responses within those bins across FI trials, and then we used the following equation:

\[
I = \frac{7R_8 - 2\sum_{i=1}^{7} R_i}{8R_8}
\]

where \(R_8\) corresponds to the total number of responses across all eight bins and \(R_i\) corresponds to the total number of responses from the first bin to the \(i^{th}\) bin. Using Equation 3, index of curvature \((I)\) can range from -0.875 to +0.875, with a negative value indicating that most responses occurred at the beginning of the interval, a value of 0 indicating that an equal number of responses occurred across all bins (indicating a lack of
temporal control), and a positive value indicating that most responses occurred at the end of the interval. We anticipated positive values for index of curvature which would indicate accelerated patterns of responding, a form of temporal control that is typical of fixed-interval schedules (Fry et al., 1960).

Next, we conducted two linear mixed models (LMMs) to assess temporal control during exposure training between rats in the ITC and Yoked-Delay groups. The first model was used to ensure that rats in each group showed similar levels of temporal control at the end of exposure training. This model included index of curvature from the last 6 sessions of exposure training (i.e., when choice was deemed stable among rats in the ITC group) with fixed effects of group (categorical), delay-block (categorical), and their two-way interaction. We treated delay as a categorical predictor because, for significant group × delay interactions, we were primarily interested in comparing group means within delay-blocks rather than comparing the slope effects for delay between groups. The second model was an exploratory LMM to examine longitudinal changes in temporal control. Specifically, we included index of curvature from all sessions of exposure training with fixed effects of group (categorical), delay-block (categorical), session (continuous), a quadratic term for session (continuous), and their two-, three-, and four-way interactions. We included a quadratic term for session to capture non-linear trends in index of curvature because we expected temporal control to develop across time until rats reached an asymptotic level which would be captured by the quadratic term.

**ITC Choice.** For rats in the ITC group, we analyzed data from the increasing-delay ITC task using a similar analytical approach as we did for the increasing-delay DoG task during Experiment 1. First, we organized choice data from each trial in terms
of choices for the smaller-immediate (1-pellet) option and larger-later (3-pellet) option. Because the dependent variable was binary, we analyzed choice data using a generalized linear mixed model (GLMM) with a logit link (Young, 2018). We included fixed effects of delay (continuous), session (continuous), and their two-way interaction in the model. In addition, we log-transformed, standardized, and centered the delays because this has been shown to improve model fit and convergence in previous studies (Haynes & Odum, 2022; Young et al., 2012; Young, 2018). Finally, we calculated area under the curve (AUC) as in Experiment 1 using Equation 2 so that we could visualize changes in choice across time.

**Increasing-Delay DoG Task**

We examined choice data from the increasing-delay DoG task with a GLMM using the same approach described in Experiment 1. As in Experiment 1, we also calculated initial and final choice AUC using Equation 2.

**Supplemental Analyses**

As in Experiment 1, we conducted analyses on other measures (center & choice response latencies in exposure training and defection latencies & counts in the DoG task) and present these analyses and their discussion in the supplemental file on OSF.

**Justification of Sample Size**

Sample sizes were estimated via simulations using the `mixedpower` and `simr` packages in R (Green & MacLeod, 2016; Kumle et al., 2021; R Core Team, 2019). The power analysis was conducted for an LMM on the number of defection responses
between groups. Based on prior work employing the increasing-delay ITC task (Haynes & Odum, 2022, Experiment 2), the average effect size for the effect of group (both the main effect & its interactions) was estimated to be very large ($d = 2.21$). Because the procedures in the present study differed from those of Haynes and Odum, we reduced the effect sizes for the main effect of group and its interactions by 50%. Defection responses are more frequent in latter delay blocks (i.e., when the delays are longer and the opportunity to defect is also longer); therefore, we focused our power analysis on the group × delay-block interaction. The power analysis revealed that 7 rats per group would be needed for a .87 level of power for the group × delay-block interaction. We chose to include one additional rat per group to ensure an equal number of male and female rats per group and in case of attrition.

## Results

### Exposure Training

**Assessment of Temporal Control**

During exposure training, we found evidence that temporal control developed across time among rats in the ITC and Yoked-Delay groups. To illustrate, Figure 8 shows index of curvature as a function of session for rats in both groups during exposure training. Overall, index of curvature changed very little across sessions at the 4- and 8-s delays but tended to increase, to a small degree, at the 16- and 32-s delays. In addition, rats in the ITC and Yoked-Delay groups showed similar levels of temporal control throughout exposure training. When rats in the ITC group met behavioral stability at 34

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16 The overall conclusions from analyzing the number of defection responses were similar to the GLMMs on choice data and the GLMMs provide a more detailed description of the data; therefore, we omit the LMMs on defection responses here but present the analysis and results in the supplemental file.
sessions of exposure training, we tested whether index of curvature differed between-groups during the last 6 sessions (i.e., when choice was deemed stable among rats in the ITC group). We found no evidence of between-group differences with respect to index of curvature during these last 6 sessions, $p = .93$ for the main effect of group and $p = .86$ for the group $\times$ delay-block interaction; therefore, we transitioned all rats to amount-discrimination training II followed by the delay of gratification task. Next, we describe the LMM used to explore longitudinal changes in index of curvature.

**Figure 8**
*Index of Curvature During Exposure Training (Experiment 2)*
Note. Index of curvature (Equation 2) as a function of session for each delay-block (columns) during exposure training for rats in the ITC and Yoked-Delay groups. Data points represent index of curvature for the group (top row) and for matched rats in each group (lower rows). Group data points are averages across subjects. Datapaths are predicted values at the group and individual-subject levels, generated from the final LMM on index of curvature. Error bands in the top panel (i.e., group-predicted values) represent 95% confidence intervals. Note that the y-axes differ for each row to illustrate changes in index of curvature across time within each matched pair. The horizontal dashed line represents an index of curvature of 0 (i.e., lack of temporal control).

Figure 8 also shows predicted values according to the final LMM fit to index of curvature values from all sessions of exposure training (see Table 3). This model included a random slope effect of session and session² because doing so significantly improved model fit, $\chi^2(2) = 56.90, p < .001$ and $\chi^2(3) = 43.07, p < .001$, respectively, allowing for changes in index of curvature across time to vary for each rat in the model. We did not find significant between-group differences in index of curvature (all $ps > .05$ for the main effect of group & the interactions with group). In addition, we did not find a significant main effect of session, $\chi^2(1) = 0.71, p = .40$; however, we did find a significant delay-block × session interaction, $\chi^2(3) = 26.25, p < .01$. This interaction captures the finding that index of curvature tended to increase in the latter delay blocks (i.e., at the 16- & 32-s delays). To further examine this interaction, we conducted a simple slopes analysis to identify which delay-blocks showed significant changes across time. This analysis revealed that index of curvature significantly increased across sessions at the 16- and 32-s delay-blocks (both $ps < .05$) but not at the 4- and 8-s delay-blocks (both $ps > .05$). In addition to the significant delay-block × session interaction, we also found a significant main effect of delay-block, $\chi^2(3) = 75.86, p < .001$; however, this effect should be interpreted cautiously given the significant two-way interaction. No other main effects
or interactions were significant (all $p > .05$).

Table 3

| Results from the final LMM on index of curvature from exposure training (Experiment 1) |
|---------------------------------|-------|-----|
| Fixed Effects                   | $\chi^2$ | df | $p$   |
| Intercept                       | 62.91  | 1   | <.01 |
| Delay-Block                     | 75.86  | 3   | <.01 |
| Group                           | 0.15   | 1   | .70  |
| Session                         | 0.71   | 1   | .40  |
| Session$^2$                     | 0.25   | 1   | .61  |
| Delay-Block $\times$ Group      | 3.09   | 3   | .38  |
| Delay-Block $\times$ Session    | 26.25  | 3   | <.01 |
| Group $\times$ Session          | 0.05   | 1   | .83  |
| Delay-Block $\times$ Session$^2$| 2.72   | 3   | .44  |
| Group $\times$ Session$^2$      | 0.21   | 1   | .65  |
| Delay-Block $\times$ Group $\times$ Session | 1.00 | 3 | .80 |
| Delay-Block $\times$ Group $\times$ Session$^2$ | 0.96 | 3 | .81 |

Random Effects

<table>
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</thead>
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</tr>
<tr>
<td>Session$^2$</td>
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</tr>
<tr>
<td>Residual</td>
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</table>

*Note.* For simplicity, we have omitted coefficients from this table, but note that the fixed effects of delay-block and group have multiple levels.

**ITC Choice**

For rats in the ITC group, choice of the larger-later (3-pellet) option decreased as the delay to that option increased as is typical in increasing-delay intertemporal choice tasks (e.g., Evenden & Ryan, 1996). The top panels in Figure 9 show the proportion of choices for the 3-pellet option as a function of delay from the increasing-delay ITC task during the first and last session of the task. As the figure shows, choice of the 3-pellet option decreased as the delay increased. In addition, choices for the 3-pellet option tended to decrease at the longer delays between the first and last session of the task. Next, we describe the results of the GLMM used to analyze choice data during this condition.
for the ITC group.

Figure 9
Choice Data for Rats in the ITC Group During Exposure Training (Experiment 2)

Note. Top panels: Proportion of choices for the larger-later (3-pellet) option as a function of delay during the first and last session of exposure training for each rat in the ITC group. Individual-subject data are presented as gray datapaths and group medians are presented as black datapaths. Middle panels: Probability of choosing the 3-pellet option as a function of delay during the first and last session of exposure training according to the final GLMM. Error bands represent 95% confidence intervals. Bottom panel: Area under the curve as a function of session. Individual-subject data are presented as gray, unconnected data points. Group medians are presented as black, connected data points.

Table 4
Results from the final GLMM on choice data for rats in the ITC group during exposure training (Experiment 2)

<table>
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<th>Fixed Effects</th>
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<th>$\chi^2$</th>
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<th>p</th>
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<tbody>
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<td>Intercept</td>
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<td>9.08</td>
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<td>.003</td>
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<tr>
<td>Log Delay</td>
<td>-10.05</td>
<td>155.59</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Session</td>
<td>0.10</td>
<td>0.01</td>
<td>1</td>
<td>.91</td>
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<tr>
<td>Log Delay × Session</td>
<td>-10.58</td>
<td>23.22</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>
Random Effects                  Variance  SD
---------  ------  ------
Subject    2.17   1.47
Log Delay  5.07   2.25
Session    6.42   2.53
Log Delay × Session  37.81   6.15

The middle panels of Figure 9 show the predicted probability of choosing the larger-later (3-pellet) option as a function of the delay to that option according to the final GLMM. This model included random slope effects for delay, session, and the delay × session interaction because these effects significantly improved model fit (all ps < .001; see Table 4), allowing for the joint effect of delay on choice and changes in choice across time to vary for each rat. This model showed that choice of the 3-pellet option decreased as a function of delay according to a significant main effect of delay, \( \chi^2(1) = 155.59, p < .001 \). The model did not reveal a significant main effect of session, \( \chi^2(1) = 0.01, p = .91 \); there was, however, a significant delay × session interaction, \( \chi^2(1) = 23.22, p < .001 \), indicating that choice of the 3-pellet option decreased at longer delays across time.

The GLMM described above indicates that choices for the larger-later (3-pellet) option decreased during exposure training; however, this finding should be interpreted in a broader context. To illustrate, the bottom panel of Figure 9 shows AUC as a function of session for rats in the ITC group during exposure training. This panel shows that AUC decreased (i.e., choices for the 3-pellet option decreased) rapidly until approximately session 8 of exposure training. After this initial decrease in the beginning of training, AUC was relatively stable throughout the rest of training. This panel also highlights the high degree of between-subject variability in choice across time. Specifically, the range of AUC values tends to widen across sessions. Thus, although choices for the 3-pellet option tended to decrease across time, these decreases tended to occur early in training.
Furthermore, we found a high degree of between-subject variability in choices for the 3-pellet option. Note that the other groups of rats did not have an opportunity to choose between the 1-pellet and 3-pellet option, and so there are no choice data to present for those groups for this condition.

**Increasing-Delay DoG Task**

**Choice**

Next, we examined choice data from the increasing-delay DoG task for the ITC, Yoked-Delay, and Yoked-Amount groups. Figure 10 show the proportion of initial and final choices for the larger-later (3-pellet) option as a function of delay during the first and last 3 sessions of the increasing-delay DoG task for each group of rats. Across all groups, initial and final choices for the 3-pellet option decreased as the delay to receiving that option increased, as in Experiment 1 (see also Haynes & Odum, 2022). During the first 3 sessions of the task, rats across all group defected on their choice of the 3-pellet option, indicated by the difference in the initial and final choice functions depicted in the left panels of Figure 10. The difference between the initial and final choice functions was larger for rats in the Yoked-Amount group than for rats in the ITC and Yoked-Delay groups, indicating that the Yoked-Amount group defected more frequently than the ITC and Yoked-Delay groups. As Figure 10 shows, initial choices for the 3-pellet option decreased more as a function of delay among rats in the ITC and Yoked-Delay groups which resulted in fewer deflection responses, with the exception of one rat in the Yoked-Delay group (YD-33; open squares). Across all groups of rats, initial choices for the 3-pellet option decreased across time, resulting in fewer deflection responses. This finding is indicated by the smaller differences between the initial and final choice functions during
the last 3 sessions of the task depicted in the right panels of Figure 10. Thus, rats in the Yoked-Amount group tended to defect more frequently than rats in the ITC and Yoked-Delay groups; however, these defection responses decreased across time until by the last sessions, rats across all groups rarely made defection responses.

Figure 10
Choice Data from the Increasing-Delay DoG Task (Experiment 2)

Note. Proportion of initial and final choices for the larger-later (3-pellet) option as a function of delay during the first and last 3 sessions (columns) of the DoG task for the ITC, Yoked-Delay, and Yoked-Amount groups (rows). Group medians are presented as darker datapaths and individual-subject data are presented as lighter datapaths. In addition, data have been jittered on the x-axis so that all are visible.

To further illustrate the changes in choice across time during the DoG task, Figure 11 shows initial and final choice AUC as a function of session for each group of rats. Similar to what can be seen in Figure 10, initial choices for the larger-later (3-pellet) option were higher than final choices for that option among all groups of rats, but the difference between initial and final choices tended to be larger for rats in the Yoked-Amount group than for rats in the ITC and Yoked-Delay groups. In addition, this figure
further illustrates that initial choices for the 3-pellet option decreased across time, and that final choices for that option were relatively stable across time. Finally, this figure shows that YD-33 (open squares) had a higher initial choice AUC across much of the DoG task than all other rats, including those in the ITC and Yoked-Amount groups. Although this rat frequently chose the 3-pellet option initially, this rat rarely waited for the 3-pellet option, resulting in a high number of defections for this rat throughout the DoG task. Upon further inspection of this rat’s data during exposure training, this rat showed the poorest temporal control as indicated by index of curvature (see Figure 9).17 Because data from this rat were extreme during both conditions, we conducted our GLMM analysis of the choice data for the increasing-delay DoG task with and without this rat (described next).

17 This rat had the lowest index of curvature in the 4-, 8- and 16-s delay-blocks, averaged across the last 6 sessions of exposure training (when choice was deemed stable for rats in the ITC group), and the lowest overall index of curvature, averaged across delay-blocks. Furthermore, this rat had the lowest random slope coefficient for the session predictor in the longitudinal LMM, indicating that this rat showed the slowest increases or fastest decreases in index of curvature across time. Although some other rats also showed evidence of poor temporal control (e.g., ITC-41; see Figure 9), YD-33 was the most extreme in these respects.
Figure 11

AUC During Increasing-Delay DoG Task (Experiment 2)

Note. Initial and final choice AUC as a function of session for rats in the ITC, Yoked-Delay, and Yoked-Amount groups (rows). Individual-subject data are presented as unconnected data points. Group medians are presented as connected data points.

Figure 12A shows the results of the final GLMM fit to the choice data from all rats in the increasing-delay DoG task. This model included random slope effects for delay, choice type, and session because doing so significantly improved model fit (all $p$ < .001; see Table 5). Thus, the final model allowed the effect of delay on choice, differences between initial and final choices, and changes in choice across time to vary for each rat. This model revealed a significant main effect of delay, $\chi^2(1) = 325.40, p < .001$, indicating that initial and final choices for the larger-later (3-pellet) option decreased as a function of delay. Other significant main effects, as well as two- and three-way interactions, were detected (see Table 5); however, of primary interest was a significant four-way interaction between delay, choice type, session, and group, $\chi^2(2) = 21.67, p < .001$. The model without subject YD-33 revealed qualitatively similar results.
in terms of main effects and interactions (importantly, the four-way interaction; see supplemental file); however, the models differed with respect to the follow-up comparisons we performed to describe the four-way interaction.

**Figure 12**

*Results of GLMM on Choice Data from Increasing-Delay DoG Task (Experiment 2)*

*Note.* Top panels (A): Predicted probabilities of an initial and final choice for the larger-later (3-pellet) option as a function of delay during the first and last 3 sessions of the DoG task for each group of rats (rows), generated from the GLMM with all subjects (solid datapaths) and the GLMM without YD-33 (dashed datapaths). Error bands represent 95% confidence intervals for the GLMM with all subjects. Bottom panels (B): Estimated differences between the probability of an initial vs. final choice of the 3-pellet option as a function of delay for each group of rats, generated from the GLMM with all subjects (bars) and the GLMM without YD-33 (white datapoints). Upper error bars represent upper limits for the 95% confidence intervals for the GLMM with all subjects. Note that the delays are presented ordinally on these panels.

**Table 5**

*Results from the final GLMM on choice data during the increasing-delay DoG task (Experiment 2)*

<table>
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<th>Fixed Effects</th>
<th>$\chi^2$</th>
<th>df</th>
<th>$p$</th>
</tr>
</thead>
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<tr>
<td>Intercept</td>
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<tr>
<td>Log Delay</td>
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<td>&lt;.001</td>
</tr>
<tr>
<td>Session</td>
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<td>.35</td>
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<tr>
<td>Choice Type</td>
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</tr>
<tr>
<td>Group</td>
<td>0.22</td>
<td>2</td>
<td>.90</td>
</tr>
<tr>
<td>Log Delay $\times$ Session</td>
<td>7.76</td>
<td>1</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>
Of primary interest in this experiment were between-group differences in defection responses. Therefore, to explore the four-way interaction, we made between-group comparisons using the same approach described in Experiment 1. To do this, we first calculated within-group differences in the probability of an initial vs. final choice for the larger-later (3-pellet) option and then we compared these within-group differences between each group of rats at the 4-, 8-, 16-, and 32-s delays during the first and last 3 sessions of the DoG task. These within-group differences are displayed in Figure 12B, described further below.

During the first 3 sessions of the DoG task, rats in the ITC and Yoked-Delay groups had smaller differences between initial and final choices for the larger-later (3-pellet) option than rats in the Yoked-Amount group (see left panels in Figure 12B). The model with all subjects showed that rats in the Yoked-Amount group defected significantly more often than rats in the ITC group at the 8-, 16-, and 32-s delays and significantly more often than rats in the Yoked-Delay group at the 16-s and 32-s delays.
during the first session of the DoG task (all $p < .05$). These between-group differences disappeared rapidly such that rats in the Yoked-Amount and Yoked-Delay groups did not differ in terms of defections at any delay after the first session. Rats in the Yoked-Amount and ITC groups differed at the 8- and 16-s delays during the second session of task and no other subsequent session. For the model without YD-33, we found that rats in the Yoked-Amount group defected significantly more often than rats in the ITC and Yoked-Delay groups at the 8-, 16-, and 32-s delays during each of the first 3 sessions of the task (all $p < .05$). Across both models (i.e., the models with & without YD-33), we did not find any significant differences between the ITC and Yoked-Delay groups in terms of defections (all $p > .05$). Thus, rats in the Yoked-Amount group defected more frequently than rats in the ITC and Yoked-Delay groups at the beginning of the increasing-delay DoG task.

During the last 3 sessions of the DoG task, differences between initial and final choices for the larger-later (3-pellet) option were similar between each group of rats (see right panels in Figure 12B). The model with all subjects showed no significant differences between any group of rats during these last 3 sessions (all $p > .05$). Interestingly, the model without YD-33 showed that rats in the Yoked-Amount group defected less often than rats in the ITC group at the 4-s delay during each of the last 3 sessions of the task (all $p < .05$). As Figure 12B shows, differences between initial and final choices for the 3-pellet option at the 4-s delay were smaller for the Yoked-Amount group.

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18 This finding is counterintuitive because YD-33 was in the Yoked-Delay group, but the significant differences found in the last 3 sessions of the task were between rats in the ITC and Yoked-Amount groups. This likely occurred due to the reduction in variability associated with the fixed effects in the model without YD-33. When we examined between-group differences in the number of defection responses made between each group using an LMM without YD-33, there were no differences in defection responses between any group during the final 3 sessions (see supplemental file on OSF).
group than for the ITC group during these last 3 sessions. Figure 12A shows that these differences resulted from rats in the ITC group choosing, but not waiting for, the 3-pellet option more frequently at the 4-s delay. Overall, the differences between initial and final choices for the 3-pellet option were small during these last 3 sessions across all groups (right panels in Figure 12B) indicating that all rats showed fewer defection responses by the end of the DoG task. Thus, defection responses decreased across time as rats gained experience on the increasing-delay DoG task and by the end of the task, rats across all groups tended to rarely defect.

**Discussion**

Using the modified pre-exposure procedure, we found that rats pre-exposed to a delay progression that is identical to that of a delay of gratification task tend to defect less frequently than rats not exposed to that delay progression. Specifically, rats in the ITC and Yoked-Delay groups, who were pre-exposed to the increasing delay progression, defected less frequently than rats in the Yoked-Amount group, who were not pre-exposed to that delay progression. These results favor Rachlin (2000) and McGuire and Kable’s (2013) perspectives regarding preference reversals in which such reversals depend on one’s prior experience with the delays associated with a larger-later reward. It is important, however, to interpret our findings cautiously given the influence of one subject in the Yoked-Delay group (described further below).

Our conclusions regarding the effect of pre-exposure training on preference reversals may be ambiguous if we consider data from all subjects. Specifically, we found that rats in the Yoked-Delay group defected less often than rats in the Yoked-Amount group but to a small degree. Upon visual inspection of the data, we found that one rat
(YD-33) frequently defected throughout the increasing-delay DoG task because initial choices were insensitive to the increasing-delay progression (see Figure 11). When considering the data without YD-33, we found that rats in the Yoked-Delay group reliably defected less often than rats in the Yoked-Amount group. Undoubtedly, it is inappropriate to remove a subject’s data because it does not fit a hypothesis; however, we believe that this subject’s data were unique not only during the DoG task, but also during exposure training. Specifically, YD-33 showed the smallest development of temporal control across time during exposure training and the poorest temporal control by the end of exposure training. It is possible that this lack of temporal control resulted in more frequent defections in the DoG, a finding that would be consistent with Rachlin (2000) and McGuire and Kable’s (2013) perspectives regarding preference reversals. Thus, we find it particularly important to consider our results with and without YD-33 in the context of how this rat performed across both conditions of the experiment.

**General Discussion**

The present set of experiments provide insights regarding the processes that may contribute to preference reversals that are characterized by shifts in preference from a larger-later reward to a smaller-immediate reward after a choice of that larger reward. Our primary aim was to test predictions described by Rachlin (2000) and McGuire and Kable (2013), who suggest that preference reversals can result from changes in the expected delay to a larger-later reward while an individual is waiting for that reward. Specifically, if the expected delay to a larger-later reward increases while someone is waiting for that reward, the discounted value of the larger-later reward may fall below that of a smaller, but immediately available alternative. We sought to manipulate
temporal expectations in rats using delay pre-exposure procedures to determine whether providing rats the opportunity to learn the delays associated with a larger-later reward would reduce this form of preference reversal. Overall, we believe our findings are consistent with Rachlin and McGuire and Kable; however, our results illustrate the importance of methodological considerations in testing their predictions.

In Experiment 1, our results were not consistent with our prediction that fixed-delay pre-exposure training would reduce preference reversals in a delay of gratification task. Specifically, we predicted that rats pre-exposed to a delay progression that was identical to the progression used in a delay of gratification task would rarely defect on their choice of a larger-later reinforcer in the delay of gratification task. Contrary to our prediction, however, these rats defected more often, although not statistically significantly so, than rats pre-exposed to a delay progression that was different from the progression used in the delay of gratification task. Before concluding that these findings were inconsistent with our prediction, however, we considered the possibility that our pre-exposure procedure was ineffective in providing rats the opportunity to learn the delays to the larger-later reinforcer. Although we based our pre-exposure procedure on a procedure employed by Tosun et al. (2015), we did not obtain measures of temporal control during exposure training, limiting our ability to determine the effectiveness of our procedure. Therefore, to more rigorously test our prediction, we conducted a follow-up experiment to address this limitation.

In Experiment 2, we modified the fixed-delay pre-exposure procedure to allow us to measure temporal control and we conducted more pre-exposure training. Using this modified procedure, we found evidence of control by the pre-exposure delay progression
and that rats exposed to that delay progression tended to make fewer defection responses than rats that were not exposed to that delay progression. The results of this experiment support our prediction that preference reversals can result from changes in temporal expectations and that temporal learning plays an important role in the development of these expectations.

Although the present experiments provide insights regarding the processes involved in delay of gratification, it is important to recognize the limitations of each experiment. First, in Experiment 1, several rats did not discriminate amount on most sessions of the delay of gratification task and were thus removed from the experiment. Such removals can be prevented by conducting further sessions of the delay of gratification task for rats that do not show reliable amount-discrimination, as we did in Experiment 2 (see also Haynes & Odum, 2022, Experiment 2). Second, although Experiment 2 was an extension of Experiment 1, we cannot directly compare the results of these experiments because we modified the schedule of reinforcement and the number of sessions used in exposure training. Thus, we are unable to determine whether pre-exposure training in Experiment 2 was more effective in reducing preference reversals because of the number of training sessions or because of the schedule of reinforcement. Third, in Experiment 2, our results are somewhat ambiguous regarding the influence of the yoked-delay pre-exposure training procedure on preference reversals if we consider the data from all subjects. The results become clearer when we remove a rat that produced extreme choice data in the delay of gratification task. We believe that removing this rat was justified because this rat showed evidence of poor temporal control during exposure training, indicating that the independent variable (i.e., delay-exposure) was
ineffective in producing temporal control. To be fully transparent regarding this removal, our dataset and code for the analyses are available on OSF for interested readers. Finally, in both experiments we did not include a control lever during the delay in the delay of gratification task (i.e., when the defection lever was available); therefore, we cannot differentiate defections as a function of exploratory behavior or general locomotor activity from defections as a function of reversals in preference. However, Haynes and Odum (2022, supplemental file) used a control lever (i.e., an inactive lever) to differentiate such responses and reported that rats rarely responded on the inactive lever, suggesting that defections are more likely a form of preference reversal.

Despite the limitations, we believe that our findings provide an important step in progressing research on preference reversals and also provide a number of future directions for this area of research. First, future research should identify the important facets of pre-exposure training that produce fewer defection responses. For example, the duration of training in Experiment 2 was determined by stability criteria based on choice; however, it is possible that the duration of training may be better captured by stability criteria for other facets of behavior in exposure training (e.g., temporal control). Second, future research should explore different delay progressions in pre-exposure training. For example, our data suggest that variable-delay pre-exposure training may increase the sensitivity of initial choice behavior in the delay of gratification task, resulting in fewer defections (Experiment 1). This increased sensitivity may be advantageous for reducing defections (i.e., preference reversals) across a number of different delay progressions. Future research is also necessary to determine how to increase the overall probability of waiting for a larger-later outcome. Thus far, our data suggest that pre-exposure training
tends to influence initial choices for a larger-later outcome but not final choices for that outcome (e.g., Figure 11). Longer durations of exposure training are typically used for increasing choices of a larger-later outcome in intertemporal choice tasks for rats (Panfil et al., 2020; Renda et al., 2020); thus, longer durations of exposure training may be necessary to produce changes in final choices for a larger-later outcome in delay of gratification tasks.

In addition to the future directions described above, future research should examine between-sex differences in preference reversals in delay of gratification tasks. Following the completion of these experiments, we became aware of a recent study that found male rats tend to choose larger-later food reinforcers more than female rats in an intertemporal choice task (Hernandez et al., 2020). Because we included both male and female rats in the present study, we were also able to examine between-sex differences in choice on our tasks. When visually inspecting our data, we found that male rats in our study also chose the larger-later (3-pellet) option more than females. To illustrate, Figure 13 shows initial and final choice AUC as a function of session for male and female rats across each condition of this study. Interestingly, although male rats tended to choose the 3-pellet option more frequently than female rats in the delay of gratification task, they defected on many of those choices. These findings appear inconsistent with those of Duckworth et al. (2013) and Forzano et al. (2011) who found no sex-differences in preference reversals among children; however, if we consider what rats ultimately obtained in the delay of gratification task (i.e., final choices for the 3-pellet option), both sexes are relatively similar. Thus, male rats may choose a larger-later reinforcer more

19 Although we included both sexes, our experiments did not have sufficient power to formally evaluate sex-differences.
frequently, but they may not wait for that reinforcer when given the opportunity to defect. Future research should explore this sex difference further as it could have meaning for between-sex differences in preference reversals in people.

**Figure 13**

_AUC for Male and Female Rats Across Both Experiments_

![Figure 13](image)

*Note.* Initial and final choice AUC as a function of session for male and female rats across both experiments. Individual-subject data are presented as unconnected data points. Medians of each sex, collapsed across groups, are presented as connected data points.

A number of other future directions exist regarding preference reversals in delay of gratification. Our hope is that researchers will continue to explore these future directions as they may have implications for reducing such reversals as they relate to human health (e.g., Reyes-Huerta et al., 2018). Importantly, future research should consider the role of temporal expectations on this form of preference reversal. Our data suggest that these temporal expectations play an important role in these preference reversals, supporting Rachlin (2000) and McGuire and Kable’s (2013) perspectives on why these preference reversals occur. As Rachlin stated, “How long do you wait before giving up and hailing a taxi? It depends on when you estimate that the next bus will come” (p. 46). Echoing his statement, “How long does the rat wait before giving up and choosing 1 pellet? It depends on when they estimate that the 3 pellets will come”.
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CHAPTER 4

CONCLUSION

Intertemporal choices represent a wide range of decisions related to many aspects of peoples’ lives. Some intertemporal choices may be trivial whereas others may be more serious. Although intertemporal choice has been widely studied across multiple disciplines (e.g., psychology, ecology, & economics), there are many facets of intertemporal choice that remain unexplored. In the experiments described in the preceding chapters, I sought to investigate one such facet: preference reversals characterized by shifts in preference from a larger-later reward to a smaller-immediate reward after a choice of that larger-later reward. The purpose of these studies was to provide the methodological and conceptual foundations for further understanding this facet of intertemporal choice so that future research could identify methods of reducing these preference reversals as they relate to human health.

In Chapter II, I described a study in which I developed and tested a procedure that would allow me to measure preference reversals in rats (Haynes & Odum, 2022). To do this, I first modified a procedure introduced by Reynolds et al. (2002) that was used to show that rats will ‘defect’ (i.e., reverse their preference) on their choice of a larger-later reinforcer in an adjusting-amount delay of gratification task. After developing this modified procedure, I tested rats on that procedure. In Experiment 1 (Chapter II-1), I replicated Reynolds et al.’s finding that rats would reverse their preference from a larger-later reinforcer to a smaller-immediate reinforcer; however, I also found that these preference reversals (i.e., defection responses) decreased over time. In Experiment 2 of that study (Chapter II-2), I collected data that allowed me to explore why these
preference reversals decreased in the delay of gratification task during Experiment 1 according to a theoretical model developed by Reynolds and Schiffbauer (2005).

Reynolds and Schiffbauer’s (2005) Feedback Model of Delay-Related Impulsive Behavior suggests that defection responses in delay of gratification tasks represent failures in inhibitory control, and that these responses should decrease over time as individuals gain experience with the task. Specifically, when a smaller-immediate reward is available during the delay to a larger-later reward, an individual must continuously inhibit the defection response for the smaller-immediate reward during the delay. Making a defection response results in the smaller-immediate reward; however, making this response also adds a delay to that smaller reward that could have otherwise been avoided had the individual chosen the smaller option initially. If the individual repeatedly does not inhibit the defection response, the Feedback Model suggests that the individual will eventually learn to avoid these unnecessary delays by choosing the smaller-immediate option initially instead of choosing the larger-later option and defecting. The results from Chapter II-1 were consistent with the Feedback Model such that experience on the delay of gratification task (i.e., with making defection responses) was associated with fewer defections over time.

In Chapter II-2, I was able to determine whether prior experience with making defection responses is necessary for those responses to decrease according to the Feedback Model (Reynolds & Schiffbauer, 2005). Rats completed an intertemporal choice task that was modeled after the delay of gratification task, but without the availability of the defection response. After completing the intertemporal choice task, rats were switched to the delay of gratification task. During the delay of gratification task, rats
rarely made defection responses, indicating that experience with making or withholding defection responses is unnecessary for those responses (i.e., preference reversals) to decrease in a delay of gratification task. Thus, the results from Chapter II-2 were inconsistent with predictions from the Feedback Model.

The results from Chapter II showed that defection responses in a delay of gratification task are rare after rats gain experience on the delay of gratification task and on an intertemporal choice task employing the same delay progression. From these findings, I hypothesized that the decrease in defections occurred because rats had gained experience with the delays to the larger-later reinforcer, and not because they had gained experienced with the defection response. My hypothesis was based on the perspectives of Rachlin (2000) and McGuire and Kable (2013) who suggest that preference reversals can occur when the expected delay to a larger-later reward changes while an individual is waiting for that reward. Specifically, if the expected (i.e., estimated) delay to a larger-later reward increases beyond that of the original expected delay, the discounted value of that reward may fall below that of the smaller-immediate reward and thus we would expect a preference reversal to occur. Importantly, these ‘temporal expectations’ are developed based on one’s prior experience with the delayed outcome. The data from Chapter II were consistent with the perspectives of Rachlin and McGuire and Kable because if rats had learned the delays to the larger-later reinforcer during the delay of gratification task and the intertemporal choice task, temporal expectations should have been stable after the larger reinforcer was chosen in the delay of gratification task. Stable temporal expectations should translate to stable preferences such that when the larger-
later reinforcer was chosen, we would not expect preference to shift in favor of the smaller-immediate reinforcer, thus resulting in fewer defections.

In Chapter III, my goal was to further extend the findings of Chapter II by testing predictions from Rachlin (2000) and McGuire and Kable’s (2013) perspectives regarding preference reversals. Specifically, I used delay pre-exposure procedures to provide rats the opportunity to learn the delays to a larger-later reinforcer, prior to the increasing-delay delay of gratification task. For some rats, the delay-progressions during exposure training were identical to that of the delay of gratification task. For these rats, if temporal control generalized from exposure training to the delay of gratification task, temporal expectations during the delay of gratification task should have matched the expectations developed during exposure training. Thus, when these rats chose the larger-later reinforcer during the delay of gratification task, I expected preference to be stable during the delay and that these rats would rarely defect. For other rats, the delay-progressions during pre-exposure training were different from that of the delay of gratification task. For these rats, temporal expectations during the delay of gratification task should not have matched the expectations developed during exposure training. Thus, when these rats chose the larger-later reinforcer during the delay of gratification task, I expected preference to be unstable (i.e., more likely to shift) during the delay and that these rats would defect more frequently.

Overall, the findings from Chapter III indicate that providing rats the opportunity to learn the delays to a larger-later reinforcer results in fewer defection responses in a delay of gratification task; however, my findings also highlight important methodological considerations regarding how pre-exposure procedures should be implemented. In
Experiment 1 (Chapter III-1), I found that when rats were pre-exposed to a delay-progression that was identical to that of the delay of gratification task, this procedure did not reduce defection responses. These findings were inconsistent with my prediction, but I did not measure temporal control. Thus, it is possible that in Experiment 1, my pre-exposure procedure was ineffective in providing rats the opportunity to learn the delays to the larger-later reinforcer and I did not have a measure to determine whether this learning occurred. In Experiment 2, I modified the pre-exposure procedure to include a measure of temporal control and I conducted more pre-exposure training so that I could more rigorously test my prediction. With this modified pre-exposure procedure, I found evidence of temporal control during pre-exposure training among rats that were exposed to the delays from the delay of gratification task. Subsequently, these rats defected less frequently than rats that were not exposed to delays during pre-exposure training. Thus, Chapter III indicates that providing rats the opportunity to learn the delays associated with a larger-later reinforcer through pre-exposure training can reduce defections, but that the structure and/or the length of pre-exposure training plays an important role.

Overall, the findings from both chapters indicate that temporal learning may influence preference reversals, supporting perspectives suggesting that these reversals can result from shifts in temporal expectations (McGuire & Kable, 2013; Rachlin, 2000). Importantly, such findings may have implications for influencing preference reversals in people in socially important ways. For example, when an individual chooses to quit smoking cigarettes for the delayed health-benefits of abstention (e.g., improved lung function; American Lung Association, 2020), preference may shift in favor smoking cigarettes (a relapse) if the individual estimates that those health-benefits are further in
time than initially expected. Although many processes contribute to relapse (see Reyes-Huerta et al., 2018; Venniro et al., 2020), shifts in temporal expectations should be considered as one of these processes that may contribute. Based on my data, one method of reducing relapse could be to inform an individual of the timeline for expecting the delayed benefits associated with an adaptive choice. It should be noted, however, that providing such information could also reduce the likelihood that the individual will choose the delayed outcome in the first place, if the delay is longer than the individual is willing to wait. My data, in which rats showed fewer preference reversals by choosing the larger-later reinforcer less, indicate that this is a likely outcome of providing such information. Thus, an important future direction will be to identify methods that not only provide individuals with temporal information regarding a delayed outcome, but that also increase the likelihood that they will choose the delayed outcome after receiving that information.

Although the findings from both chapters suggest that temporal expectations play a role in preference reversals, it is important to recognize the limitations of these findings. First, although my results are consistent with perspectives suggesting that shifts in temporal expectations can cause preference reversals (Rachlin, 2000; McGuire & Kable, 2013), other processes likely contribute to these preference reversals as well. For example, research employing delay of gratification tasks in children (e.g., the marshmallow test; Mischel & Ebbesen, 1970) indicate that performance on such tasks is related to inhibitory control (Carlson et al., 2014; Yu et al., 2016). Because my focus was on the role of temporal expectations on defections in the increasing-delay delay of gratification task, further research is necessary to determine how other processes, such as
inhibitory control, may influence defections in this task. Second, although the increasing-delay delay of gratification task is structured similar to an intertemporal choice task (e.g., Evenden & Ryan, 1996), it is unclear how choice in these tasks may be related. Establishing this relation was the original aim of Chapter II; however, because I found strong order effects, this made my original analytical plan (i.e., correlating choice between tasks) untenable. Determining how choice is related between these two tasks may be important for identifying the facets of impulsive behavior that are captured by the delay of gratification task but not by the intertemporal choice task.

Despite these limitations, Chapters II and III provide the foundation for further studying preference reversals that are characterized by shifts in preference from a larger-later reward to a smaller-immediate reward after a choice of the larger reward. Chapter II provides the methodology for studying these preference reversals using a delay of gratification task in a preclinical rat model. In Chapter III, I used this preclinical rat model to test theoretical predictions regarding why these preference reversals occur and I identified a procedure that may reduce them. My findings point to multiple directions for future research which will be necessary for further testing theoretical predictions regarding this form of preference reversal and for translating these findings into methods for reducing these preference reversals in people. As preference reversals may be related to socially significant health behavior in people (e.g., relapse; Reyes-Huerta, 2018), these future directions will be important steps in developing interventions to prevent these reversals as they relate to human health (Venniro et al., 2020).
Acknowledgments

I have no known conflicts of interest. I would like to thank Amy Odum, Casey Frye, Annie Galizio, D. Perez, Mariah Willis-Moore, Devanio Cousins, and the many undergraduate students who worked in our lab for helping me complete these studies. These studies were supported by the Society for the Advancement of Behavior of Analysis, Psi Chi, and Utah State University.
References


Curriculum Vitae
Jeremy M. Haynes, Ph.D.
jeremy.haynes@usu.edu
(912) 547-4570

Education
2022  Ph.D. in Psychology
Dissertation: Preference Reversals in Delay of Gratification
Utah State University
Department of Psychology
Advisor: Amy L. Odum, Ph.D.

2022  Certificate in Advanced Research Methods and Quantitative Analysis
Utah State University
Emma Eccles Jones College of Education and Human Services

2015  B.S. in Psychology
Armstrong State University
Department of Psychology
Advisor: Jonathan E. Roberts, Ph.D.

Skills
8+ years  Designing and Conducting Psychological Research: Managed studies examining research questions ranging from how to improve college-student learning to how rats make decisions between delayed outcomes.

7+ years  Teaching College-Level Courses: Served as a teaching assistant and instructor for undergraduate- and graduate-level courses on subjects such as research methods, statistics, and behavioral psychology.

5+ years  R Statistical Programming: I have used R to analyze complex behavioral datasets to answer questions regarding human and non-human animal behavior.20

5+ years  Medstate Notation Programming: I have used Medstate Notation to program experiments for collecting data from rats and pigeons to answer a range of questions regarding the fundamental processes involved in behavior.10

1+ years  Python Programming: I have used Python to program experiments for collecting data on how people make decisions between delayed outcomes.

Awards
Summer 2022  APA Division 25 Innovative Student Research Award: $250
Spring 2019  Walter R. Borg Scholarship and Research Productivity Award: $3,250
Spring 2015  Armstrong State University Writing Competition: $50

20 For samples of code, see https://osf.io/wup57/?view_only=7980626c899a4b208cf313b66a000b7c
Spring 2015  Dr. Stu Worthington Award for Outstanding Senior Student in Psychology
Fall 2014  Armstrong State University Undergraduate Research Grant: $111.35

**Grants**

- **Summer 2020**  Preference Reversals in Delayed Gratification: $1,493.00 (Haynes, PI)
  - Psi Chi Graduate Research Grant (External funding)
- **Summer 2020**  The Influence of Predation Risk on Coyote Behavior: An Application of the Matching Law: $962.38 (Haynes, PI)
  - USU Graduate Research and Creative Opportunities Grant (Competitive Internal funding)
- **Summer 2018**  Can Rats Maintain their Preference for the Larger-Later? $2,383.28
  - Society for the Advancement of Behavior Analysis Innovative Student Research Dissertation Grant (External funding)

**College-Funded Projects**

- **Spring 2022**  Preference Reversals in Delay of Gratification: $2,998.51 (Haynes, PI)
  - Utah State University, College of Education and Human Services Graduate Student Research Award (Internal funding)
- **Spring 2018**  The Effects of Pretrial Reward Magnitude on Delay Discounting: $1,942.16 (Haynes, PI)
  - Utah State University, College of Education and Human Services Graduate Student Research Award (Internal funding)

**Research Experience**

- **2016 - Present**  **Graduate Research Assistant**
  - Utah State University
  - USU Behavior Laboratory
  - Supervisor: Amy L. Odum, Ph.D.
  
  My experience in this laboratory has led to authorship on eight publications, two of which I am the first author on. I am currently writing the manuscript for an experiment with humans examining framing effects in the discounting of delayed losses. I have gained multiple skills in this laboratory including writing manuscripts and grants, developing research projects involving human and non-human animal subjects, as well as programming skills in R, Python, and Medstate notation. Finally, I have served as a research supervisor to multiple undergraduate students and have mentored several students in presenting research at USU’s annual research symposium.

- **2019 - 2020**  **Statistical Consulting Assistant**
  - Utah State University
  - Statistical Consulting Studio
  - Supervisor: Sarah Schwartz, Ph.D.

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21 Funding partially matched by Utah State University Department of Psychology
I assisted students and faculty at multiple stages in the design, analysis, and publication of psychological research. In addition, I provided guidance in using R statistical software to prepare and analyze data for publication and for graduate coursework. Finally, I gained experience leading graduate-level lectures on statistics.

2014 - **Undergraduate Research Assistant**
2016 Armstrong State University
Researching Engagement in Active Learning (R.E.A.L.) Laboratory
Supervisors: Joshua L. Williams, Ph.D. & Nancy G. McCarley, Ph.D.
My experience in this laboratory led to authorship on five publications, two of which I am the first author on. I collected and collaborated on analyzing data across several experiments examining how students can increase their academic performance by engaging in active learning strategies.

**Teaching Experience**

2018 - **Graduate Instructor (Instructor of Record; USU)**
Present
Psychological Statistics: I provided an introduction to and extension of the statistical methods that students learned from previous courses in psychological statistics. In doing so, I taught students the mechanics of statistical tests through hand calculations as well as software implementations of the tests in SPSS.

Advanced Behavior Analysis: I lectured on complex material including theories of learning and the research that led to these prominent theories. In addition, this course involved a concurrent pigeon laboratory where we explored questions involving behavioral variability and reward value.

2016 - **Graduate Teaching Assistant (USU)**
2018
Advanced Behavior Analysis: I coordinated the laboratory portion of this course to provide students with experience in conducting behavioral research with non-human animals (pigeons). In addition, I was in charge of managing the health of the pigeons and maintaining institutional animal care and use committee (IACUC) standards of care for the pigeons and the laboratory.

2014 - **Supplemental Instructor (ASU)**
2015
Statistics for the Behavioral Sciences: I designed exercises aimed at providing students with practice on using SPSS to run t-tests and many forms of ANOVA.

Introduction to Psychological Research: I facilitated students’ learning of the statistical and research procedures used in psychology and trained students to conduct an experiment with human participants that followed IRB regulations.

Careers and Professional Skills in Psychology: I assisted students in learning the preliminary skills required for making inferences from
psychological research using statistics and introduced students to SPSS for conducting statistical tests.

**Peer-Reviewed Publications**


Corbetta, D., Williams, J. L., & **Haynes, J. M.** (2016). Bare fingers, but no obvious influence of “prickly” Velcro! In the absence of parents’ encouragement, it is not clear that “sticky mittens” provide an advantage to the process of learning to reach. *Infant Behavior and Development, 42,* 168-178.


**Book Chapters**


**Paper Presentations**


use: Human and rat studies. Oral presentation delivered at the annual Winter Conference on Learning and Behavior, Logan, UT.


at the annual convention of the Association for Behavior Analysis International, Denver, CO.


Haynes, J. M. (2015, April). Examining relevant information in students’ notes recorded during and after a lecture. Oral presentation delivered at the annual Armstrong Student Scholars Symposium held on the campus of Armstrong State University, Savannah, GA.

Poster Presentations


Haynes, J. M., Mullin, E., & Mears, D. (2015, April). Active learning strategies for learning textbook material in traditional and nontraditional college students. Poster presented at the annual Armstrong Student Scholars Symposium held on the campus of Armstrong State University, Savannah, GA.

McKissick, K., Haynes, J. M., Whetzel, T., Long, K., Mears, D., Middleton, K., Mullin, E., Reilly, T., Giddens, M., & Harris, K. (2015, April). The impact of feedback on students’ abilities to detect relevant information on PowerPoint slides. Poster presented at the annual Armstrong Student Scholars Symposium held on the campus of Armstrong State University, Savannah, GA.

Saxon, B. & Haynes, J. M. (2015, April). Student coping strategies as predictors of academic burnout. Poster presented at the annual Armstrong Student Scholars Symposium held on the campus of Armstrong State University, Savannah, GA.

Whetzel, T., Reilly, T., Giddens, M., & Haynes, J. M. (2015, April). The impact of providing a definition to help students identify relevant content. Poster presented at the annual Armstrong Student Scholars Symposium held on the campus of Armstrong State University, Savannah, GA.


Haynes, J. M. (2014, April). An analysis of notes taken during and after a lecture presentation. Poster presented at the annual Armstrong Student Scholars Symposium held on the campus of Armstrong State University, Savannah, GA.
Symposium held on the campus of Armstrong Atlantic State University, Savannah, GA.


**Professional Service**

**Ad Hoc Reviewer**
Cognitive Psychology
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Motivation and Emotion

**Student Presentation Evaluator**
Utah State University’s Student Research Symposium

**Professional Memberships**
Association for Behavior Analysis International
Society for the Quantitative Analysis of Behavior
Honor Society of Phi Kappa Phi
Psi Chi International Honors Society for Psychology
Professional References

Amy L. Odum, Ph.D.
Professor
Department of Psychology
Utah State University
amy.odum@usu.edu
Graduate Advisor
Member

Gregory J. Madden, Ph.D.
Professor
Department of Psychology
Utah State University
greg.madden@usu.edu
Dissertation Committee Member

Julie K. Young, Ph.D.
Associate Professor
Department of Wildland Resources
Utah State University
julie.young@usu.edu
Collaborator and Dissertation Committee Member