2018

Effects of Delay and Signals on Choice between Delayed Food Alone and Immediate Food with Delayed Shock

Forrest James Toegel

West Virginia University, fjtoegel@mix.wvu.edu

Follow this and additional works at: <https://researchrepository.wvu.edu/etd>

Part of the [Experimental Analysis of Behavior Commons](#)

Recommended Citation

Toegel, Forrest James, "Effects of Delay and Signals on Choice between Delayed Food Alone and Immediate Food with Delayed Shock" (2018). *Graduate Theses, Dissertations, and Problem Reports*. 3748.

<https://researchrepository.wvu.edu/etd/3748>

This Dissertation is protected by copyright and/or related rights. It has been brought to you by the The Research Repository @ WVU with permission from the rights-holder(s). You are free to use this Dissertation in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you must obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/ or on the work itself. This Dissertation has been accepted for inclusion in WVU Graduate Theses, Dissertations, and Problem Reports collection by an authorized administrator of The Research Repository @ WVU. For more information, please contact researchrepository@mail.wvu.edu.

Effects of Delay and Signals on Choice between Delayed Food Alone and Immediate Food with
Delayed Shock

Forrest J. Toegel

Dissertation Submitted
to the Eberly College of Arts and Sciences
at West Virginia University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in
Psychology

Michael Perone, Ph.D., Chair
Karen G. Anderson Ph.D.
Albert Berrebi, Ph.D.
Barry Edelstein, Ph.D.
Kennon A. Lattal, Ph.D.

Department of Psychology

Morgantown, West Virginia
2018

Keywords: choice, delay, aversive, shock, self-control, conflict, dual-valence, rats

Copyright 2018 Forrest J. Toegel

ABSTRACT

Effects of Delay and Signals on Choice between Delayed Food Alone and Immediate Food with Delayed Shock

Forrest J. Toegel

Much of the research in the area of self-control has examined choice between small immediate reinforcers and large delayed reinforcers, but many problems result from situations in which a single choice produces consequences of conflicting valence: Those in which the immediate outcome is reinforcing and the delayed outcome is aversive. Recent research has evaluated how preference for a large reinforcer which is followed by a delayed shock changes as a function of the delay to shock and how the intensity and duration of delayed shock affects the value of a large reinforcer. The present set of experiments investigated how the value of a food reinforcer followed by delayed shock changes as a function of the delay to shock. Instead of arranging choice between small and large reinforcers, the present experiments arranged choice between two reinforcers of equal magnitude – one of which was delivered after a delay, and the other was delivered immediately and followed by delayed shock. Rats chose between the consequences by pressing one of two levers. Using an adjusting-delay procedure, adjustments were made in the delay to food based on the rats' choices. Exclusive choice of delayed food raised the delay to food in subsequent trials; exclusive choice of immediate food with delayed shock reduced the delay to food in subsequent trials. Adjustments continued until the both consequences were chosen equally often and the delay to food stabilized. The mean delay over this stable period was taken as an estimate of the indifference point – the delay at which the delayed food alone was equal in value to the immediate food followed by delayed shock. In Experiment 1, indifference points were identified across conditions with different delays to shock. The shock devalued the immediate food to the greatest extent when the delay to shock was short, and the effects of shock weakened as the delay was raised. In Experiment 2, indifference points were identified across conditions in which either the delay to shock or the presence of a signaling procedure was manipulated. As in Experiment 1, effects of shock were greatest when the delay was short and weakened as the delay was raised. Signaling the delayed shock did not influence effects of the shock systematically. Additional analyses of the adjusting delay, latency to press each lever, and the fit of hyperbolas based on Mazur's (1987) hyperbolic discounting equation to indifference points were conducted for both experiments. The results from the present experiments are discussed in the context of laboratory research on choice that produces both reinforcing and aversive consequences and on effects of signaling aversive events.

Acknowledgements

There are several individuals to whom I am indebted for their role in my graduate training. First, I would like to thank Mike Perone – my advisor and the chair of my committee. I have learned a great deal from him and I cannot thank him enough for his mentorship. His guidance has allowed me to grow as a scientist and an individual. I am grateful to the members of my dissertation committee: Karen Anderson, Al Berrebi, Barry Edelstein, Andy Lattal, and Mike Perone for their helpful comments and suggestions on this document and for their time and good humor throughout this process. I would like to thank the professors at UW – Eau Claire who first got me interested in Behavior Analysis: Daniel Holt, Kevin Klatt, and Carla Lagorio. I thank my parents for instilling in me a passion for learning and for encouraging me to pursue my interests. Finally, I would like to thank my fiancée Cory Ann Whirtley for her enduring support. If not for her leadership, the lab would have fallen into disarray; and if not for her friendship, I would have too.

Table of Contents

Abstract.....	ii
Acknowledgements.....	iii
Table of Contents.....	iv
List of Tables.....	vi
List of Figures.....	vii
Introduction.....	1
The Delay-of-Gratification Paradigm of Self-Control.....	2
The Conflicting-Valence Paradigm of Self-Control.....	8
Effects of Signals on Delayed Consequences.....	13
Statement of the Problem.....	18
General Method.....	19
Subjects.....	20
Apparatus.....	20
Preliminary Training.....	21
Adjusting-Delay Procedure.....	22
Forced-Choice Trials.....	22
Free-Choice Trials.....	23
Trial Durations.....	23
Stability Criteria.....	24
Experiment 1.....	25
Method.....	25
Results.....	25
Indifference Points.....	25
Adjusting Delays across Blocks of Trials.....	31
Response Latencies in Forced-Choice Trials.....	33
Experiment 2.....	39
Method.....	39
Signal Training.....	41
Results.....	41
Indifference Points.....	41
Effects of Delay.....	44
Effects of Signals.....	45
Adjusting Delays across Blocks of Trials.....	48
Response Latencies in Forced-Choice Trials.....	50

General Discussion.....	57
Variables that Affect the Value of a Dual-Valence Consequence.....	58
Effects of Signaling Delayed Shock.....	59
Block-by-Block Analysis of Adjusting Delays.....	63
Response Latencies.....	66
Mazur's Hyperbolic Discounting Equation.....	68
Conclusion.....	70
References.....	72
Appendix A.....	78

List of Tables

<i>Table 1. Experiment 1.</i> Conditions differed based on the fixed delay to shock (s) for each rat (FD1-FD9). Order of conditions, indifference points (s), and the total number of sessions per condition are shown.....	26
<i>Table 2. Experiment 1.</i> Parameters (M and k) for the best-fitting hyperbola based on Mazur's equation in the initial (Series 1) and replicated (Series 2) sets of conditions for each rat and for the group of rats. The number of indifference points to which Mazur's function was fit is represented by N. VAC is the variance in the indifference points accounted for by the best-fitting hyperbola. Because only two rats (FD1 and FD4) were exposed to the 1-s delay to shock, the group means are presented both with (1-64 s) and without (2-64 s) the 1-s delay condition.....	30
<i>Table 3. Experiment 1.</i> Forced-choice latency data (25th, 50th, 75th percentile) and results of sign tests from the 96 stable blocks of initial and replicated conditions for each rat. Plus and minus signs were calculated by subtracting the forced-dual-valence latency from the forced-single-valence latency, and the right-most column shows comparisons that were significant at the .05, .01, and .001 levels. Missing p-values indicate that the test results were not significant at $p < .05$. Plus signs indicate comparisons with a longer latency to respond during single-valence trials and minus signs indicate a longer latency to respond during dual-valence trials.....	36
<i>Table 4. Experiment 2.</i> Conditions differed based on the fixed delay to shock (s) and the absence (No-Signal Conditions) or presence (Signal Conditions) of a signal for delayed shock for each rat (FD5-FD8). Indifference points (s) in each condition and the total number of sessions per condition are shown.....	42
<i>Table 5. Experiment 2.</i> Parameters (M and k) for the best fitting hyperbola based on Mazur's equation for each rat for the set of conditions without (N) and with (Y) a signal for delayed shock. The number of indifference points to which Mazur's function was fit is represented by N. VAC is the variance in the indifference points accounted for by the best fitting hyperbola.....	46
<i>Table 6. Experiment 2.</i> Adjusting delay data (mean and SD) and results of sign tests from the 96 stable blocks of No-Signal and Signal conditions. Plus and minus signs were calculated by subtracting the adjusting delay (s) in Signal conditions from the adjusting delay (s) in No-Signal conditions, and the right-most column shows the corresponding p-values. Missing p-values indicate that the test results were not significant at $p < .05$. Plus signs indicate comparisons with a longer delay in No-Signal conditions and minus signs indicate a longer delay in Signal conditions.....	47
<i>Table 7. Experiment 2.</i> Forced-choice latency data (25th, 50th, 75th percentile) and results of sign tests from the 96 stable blocks of each No-Signal and Signal condition. Plus and minus signs were calculated by subtracting the forced-dual-valence latency from the forced-single-valence latency, and the right-most column shows the corresponding p-values. Missing p-values indicate that the test results were not significant at $p < .05$. Plus signs indicate comparisons with a longer latency to respond during single-valence trials and minus signs indicate a longer latency to respond during dual-valence trials.....	51

List of Figures

- Figure 1.* Mazur's hyperbolic discounting function as conceptualized in 1987 (top-left panel) and fit to results from research on self-control with Pigeons (top-right), Rhesus Monkeys (bottom-left), and Humans with (squares) and without (triangles) opioid dependency (bottom-right). In all panels, the y-axis represents a measure of the value of a large reinforcer and the x-axis represents delay. With the exception of the lower-right panel, the different symbols used in each panel are not relevant to the present discussion..... 6
- Figure 2.* Indifference points for AD5 in the final condition at each shock intensity with a 200-ms duration. Redrawn results from Dumas (2014)..... 12
- Figure 3.* Mean response latencies of groups of college students across delays to money losses in conditions in which delayed money losses unsignaled (filled symbols; Experiment 1) and signaled (unfilled symbols; Experiment 2). The dashed line shows the mean response latencies during the unpunished baseline condition. Redrawn results from Trenholme and Baron (1975)..... 15
- Figure 4.* Indifference points for AD5 as a function of shock intensity in conditions without (filled circles) and with (unfilled circles) a signal for delayed shock. Results from unpublished work in our laboratory..... 17
- Figure 5. Experiment 1:* Indifference points (s) in initial (left, circles) and replicated (middle, squares) conditions, and in both conditions combined (right) for individual rats (top four panels) and the mean indifference points averaged across rats (bottom panels). Curves show the best-fitting hyperbolic function fit to indifference points in initial (solid) and replicated (dashed) conditions. Note. The scale on the y-axis is changed for FD9 to account for long indifference points..... 27
- Figure 6. Experiment 1:* Adjusting delay to food (s) plotted across successive blocks of trials. Phase lines indicate changes in conditions and arrows extending from the x-axis mark the starting point of the 96 blocks in which responding was judged stable. Phase labels show the fixed delay to shock (s) in each condition..... 32
- Figure 7. Experiment 1:* Latency to respond (s) during forced-choice trials in stable sessions of each condition, shown in the relative order of exposure for each rat. Bars show the median latency during forced-single-valence trials (unfilled) and forced-dual-valence trials (shaded). Error bars extend from the 25th to 75th percentiles..... 34
- Figure 8. Experiment 1:* The latency to respond (s) during forced-single-valence (top panels) and dual-valence (bottom panels) trials plotted as a function of the indifference point (s) identified in each condition. Symbols show the median of the 96 latencies aggregated over the stable sessions in each condition and the dashed line shows the best-fitting linear function. The tables in the middle-right and bottom right panels of the figure shows the slope of the best-fitting linear function and the correlation (Pearson's r)..... 37

Figure 9. Illustration of delayed shock without (left panel) or with (right panel) a signal delivered after each response on the dual-valence lever in Experiment 2..... 40

Figure 10. Experiment 2: Indifference points in conditions without (left, filled) and with (middle, unfilled) signaled delayed shock, and in both sets of conditions combined (right) for individual rats (top panels) and the mean indifference points averaged across rats (bottom panels). Curves show Mazur's hyperbolic discounting function fit to indifference points of No-Signal (solid) and Signal (dashed) conditions. Note. The scale on the y-axis is changed for FD7 to account for long indifference points..... 43

Figure 11. Experiment 2: Adjusting delay to food (s) plotted across successive blocks of trials in No-Signal (solid black line) and Signal (unfilled gray line) conditions. Phase labels show the fixed delay to shock (s) in each condition and phase lines indicate changes in conditions..... 49

Figure 12. Experiment 2: Latency to respond (s) during forced-choice trials in stable sessions across conditions in which delayed shock was not (left column) and was (right column) signaled. Bars show the median latency during forced-single-valence trials (unfilled) and forced-dual-valence trials (shaded). Error bars extend from the 25th to 75th percentiles..... 52

Figure 13. Experiment 2: The latency to respond (s) during forced-single-valence (top panels) and dual-valence (bottom panels) trials plotted as a function of the indifference point (s) identified in each condition. Symbols show the median of the 96 latencies to respond during single-valence (filled) and dual-valence (unfilled) trials aggregated over the stable sessions in each condition. The dashed lines show the best-fitting linear function. The table in the middle-right and bottom right panels of the figure shows the slope of the best-fitting linear function and the correlation (Pearson's r) of the two variables..... 54

Figure 14. Experiment 2: The latency to respond (s) during forced-dual-valence trials plotted as a function of the delay to shock (s) in each condition. Symbols show the median of the 96 latencies aggregated over the stable sessions in each condition. The dashed line shows the best-fitting linear function. The table in the bottom-right panel of the figure shows the slope of the best-fitting linear function and the correlation (Pearson's r)..... 56

Figure 15. Adjusting delays (s) across successive blocks of trials for FD1 (Experiment 1; 2-s delay to shock, initial exposure) and AD5 (Dumas, 2014). For both rats shown above, the shock that makes up half of the dual-valence consequence was 0.8 mA and lasted 200 ms. The adjusting delays from point "A" to point "C" indicate periods of predominant choice of the single-valence consequence (1 or 2 pellets, no shock). Adjusting delays from point "D" to point "F" indicate periods of predominant choice of two pellets plus delayed shock. The bracket marks the stability period. See text for further discussion of points "B" and "E." 64

Introduction

Within the experimental analysis of behavior, self-control is commonly discussed in terms of delay of gratification. In this paradigm, conflict exists between two consequences of positive valence – the production of a small reinforcer immediately or a larger reinforcer after a delay. Skinner's (1953) treatment of self-control focused on a different kind of conflict – one in which a single response produces consequences of positive valence and negative valence. For example, an individual with acid reflux disease might choose to eat a spicy meal for lunch despite a susceptibility to heartburn. This single choice produces reinforcing consequences immediately, but it also produces painful bouts of heartburn later in the day. Rather than producing this dual-valence consequence, the individual might engage in self-control by choosing to eat a less reinforcing salad instead of the spicy meal and thereby avoid future heartburn. Similarly, an experienced commuter might drive within the speed limit and thereby avoid a speeding ticket and a wise partygoer might limit consumption of alcohol and avoid a hangover the next morning.

Unfortunately for many individuals, delayed aversive consequences often fail to suppress responding that also produces immediate reinforcement. The fact that a spicy meal eventually results in heartburn is often not enough to dissuade individuals with acid reflux disease from eating delicious, spicy food. Despite the chance of a ticket, it is rare to find drivers who do not at least occasionally drive above the speed limit. And although hangovers can be avoided by drinking alcohol in moderation, a national survey by the Centers for Disease Control and Prevention showed that 16 percent of the U.S. population reported binge drinking on at least one occasion in the last 30 days (Li et al., 2011).

A great deal of research involves choice between two positive-valence consequences that differ in magnitude and delay, but very little research has investigated choice involving dual-valence consequences. The present experiments were designed to explore variables that affect choices in situations that involve dual-valence consequences – in particular, choices that produce reinforcing consequences immediately and aversive consequences after a delay. Before the present experiments are discussed, several areas of relevant research will be described, including the delay-of-gratification paradigm, the conflicting-valence paradigm, and effects of signaling delayed consequences.

The Delay-of-Gratification Paradigm of Self-Control

An individual is said to engage in self-control when they choose a larger, delayed reinforcer instead of a smaller, more immediate one – that is, when they choose to delay gratification. In contrast, choosing the smaller but more immediate reinforcer is commonly described as impulsivity. In a seminal experiment, Mischel and Ebbesen (1970) evaluated this kind of self-control by providing children with a choice between two snack options: a highly desirable option (cookies) and a less desirable option (pretzels). Each child was told that the experimenter had to leave the room and that they could either eat the pretzels or wait for the experimenter to return and have the cookies instead. The experimenter left the room until either the child ate the pretzels or 15 min elapsed. They found that about two-thirds of the children delayed gratification by waiting for the experimenter to return and getting the more desirable cookies.

In follow-up studies conducted 10 years after this initial study, Mischel and colleagues evaluated whether children who had delayed gratification were also more likely to engage in other behavior that is typically regarded as beneficial. They found that delaying gratification

was predictive of an array of beneficial outcomes, including high ratings by parents of an individuals' ability to plan, pursue goals, and resist temptation (Mischel, Shoda, & Peake, 1988) and high scores on the SAT (Shoda, Mischel, & Peake, 1990). These experiments sparked a widespread interest in the delay-of-gratification paradigm, as evidenced by the fact that a summary of Mischel's work (Mischel, Shoda, & Rodriguez, 1989) had been cited 1,279 times as of October 30, 2018 (Web of Science, 2018).

Enthusiasm for the delay-of-gratification paradigm has also extended into the animal laboratory. An early paper conducted by Ainslie (1974) used a variation of Mischel's procedure with pigeons. Sessions took place in operant chambers with one response key and lasted for 50 trials. In each trial, a pigeon could earn a food reinforcer – either a large amount (4-s access) or a small amount (2-s access). There were several conditions in this experiment, but the procedure was similar in each condition. At the start of a trial, the key was lit green for 7.5 s, turned off for 4.5 s, and then lit red for 3 s. If the pigeon pecked the key during the 3 s it was red, it earned the small reinforcer immediately; however, if the pigeon did not peck the red key, the pigeon earned the large reinforcer. All pigeons in the experiment pecked the red key reliably rather than delaying gratification. Ainslie's experiment showed that Mischel's task could be translated to the animal laboratory.

A more recent development in this area has been the application of mathematical models to describe the process leading to impulsive choice – *delay discounting*, the process by which the effects of a reinforcer are degraded by the delay until its receipt. Mazur (1987) developed a hyperbolic function to characterize this process:

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

Where V represents the value of the large reinforcer at a given delay, M represents the maximum (or undiscounted) effects of the delayed consequence, and D represents the delay to the reinforcer. The parameter k describes the rate at which the value of the reinforcer is degraded per unit of delay. The numerator used in Mazur's equation was originally represented by A (amount), but this was changed to M (maximum effects of a delayed consequence) because reinforcers in both consequences in the present experiments had equal amounts of food. Since its creation, the function has generally been accepted as a good description of how the value of a reinforcer is discounted by delay (e.g., Peterson, Hill, & Kirkpatrick, 2015; Myerson & Green, 1995; Rachlin, Raineri, & Cross, 1991).

Mazur (1987) developed a procedure to identify the point at which a large, delayed reinforcer and a small, but more immediate reinforcer have equal value. In Mazur's (1987) *adjusting-delay procedure*, pigeons chose between a small food reinforcer (2-s access) delivered relatively immediately and a large reinforcer (6-s access) after a delay that was adjusted based on the pigeon's previous choices. Choices were made by pecking response keys consistently associated with the small or large reinforcer. Sessions consisted of 16 blocks, each with four trials. The first two trials were *forced-choice trials* that ensured contact with the consequences associated with each key. In the first forced-choice trial, just one of the keys was available and a peck on that key produced the consequence normally associated with it. In the second forced-choice trial the other key was available, and a peck produced the normal consequence. The pigeon then was exposed to two *free-choice trials* in which both keys were available and the pigeon could peck either key.

Choices during free-choice trials led to adjustments in the delay to the large reinforcer in the next block of trials. If the large reinforcer was chosen both times, the delay was raised by 1 s

in the next block of trials. If the small reinforcer was chosen both times, the delay was reduced by 1 s. If each reinforcer was chosen once, the delay remained unchanged. Adjustments in the delay to the large reinforcer continued the delay to the large reinforcer was stable from session-to-session. This *indifference point* indicated the delay required to devalue the large reinforcer to the extent that it was equal to the value of the small reinforcer.

Versions of Mazur's (1987) adjusting-delay procedure have been used to study changes in reinforcer value with a variety of subjects and reinforcers. Subjects have included humans with and without intellectual disabilities (e.g., Johnson & Bickel, 2002), rats (e.g., Cardinal, Daw, Robbins, & Everitt, 2002), mice (e.g., Pope, Newland, & Hutsell, 2015), pigeons (e.g., Mazur 1987), and rhesus monkeys (e.g., Woolverton, Myerson, & Green, 2007). Additionally, the stimuli that constitute the small and large reinforcers have been different types of food (Calvert, Green, & Meyerson, 2010), amounts of food (Mazur, 1987), amounts of money (Johnson & Bickel, 2002), and amounts of hypothetical rewards including drugs, money, pizza, beer, candy, and soda (Estle, Green, Myerson, & Holt, 2007; Madden, Bickel, & Jacobs, 1999). As of October, 30 2018, more than 1300 articles on the topic of delay discounting had been published within the last five years (Web of Science, 2018), 171 of which were published in the *Journal of the Experimental Analysis of Behavior (JEAB; Wiley, 2018)*.

Figure 1 shows an illustration of the hyperbolic discounting function developed by Mazur (1987) fit to results from several experiments. The top-left panel shows the general pattern by which a large reinforcer is discounted by delay as conceptualized by Mazur (1987). The other panels in the figure show the function fit to results from (a) pigeons choosing between a small amount of food (5 or 15 pellets) delivered immediately and a large amount of food (30 pellets) delivered after a delay (top-right panel; Green, Myerson, Shah, Estle, & Holt, 2007),

Figure 1. Mazur's hyperbolic discounting function as conceptualized in 1987 (top-left panel) and fit to results from research on self-control with Pigeons (top-right), Rhesus Monkeys (bottom-left), and Humans with (squares) and without (triangles) opioid dependency (bottom-right). In all panels, the y-axis represents a measure of the value of a large reinforcer and the x-axis represents delay. With the exception of the lower-right panel, the different symbols used in each panel are not relevant to the present discussion.

(b) rhesus monkeys choosing between a small amount of saccharine (0.25 ml) delivered immediately and a large amount (4.00 ml) delivered after a delay (bottom-left panel; Freeman, Green, Myerson, & Woolverton, 2009), and (c) humans with (squares) and without (triangles) an opioid dependency choosing between a small amount of hypothetical money (\$1-\$990) available immediately and a large amount of hypothetical money (\$1000) available after a delay (bottom-right panel; Madden, Petry, Badger, & Bickel, 1997). The results from all of the subjects displayed in Figure 1 show that the value of a large reinforcer decays in a pattern resembling a hyperbola.

The popularity of the delay-of-gratification paradigm is likely due in part to the correlation between impulsive choice and a number of socially important issues (Odum, 2011), including obesity (Weller, Cook, Avsar, & Cox, 2008), gambling (Miedl, Peters, & Büchel, 2012), risky sexual behavior (Johnson & Bruner, 2011), and addiction to a variety of substances, such as heroin (Madden et al. 1997; Kirby, Petry, & Bickel, 1999), cocaine (Coffey, Gudleski, Saladin, & Brady, 2003), alcohol (Vuchinich & Simpson, 1998), and cigarettes (Bickel, Odum, & Madden, 1999). These correlations have shown that the rate by which the value of large reinforcers are discounted (k) is generally higher in individuals who engage in other kind of impulsive behavior like those mentioned above. For example, the bottom-right panel of Figure 1 shows a case in which the value of a hypothetical \$1000 was discounted more rapidly for opioid-dependent individuals than for individuals who did not use opioids. The correlations obtained using Mazur's (1987) function are potentially useful because they characterize a pattern of behavior common to many different situations involving impulsive choice.

The Conflicting-Valence Paradigm of Self-Control

A handful of studies have investigated behavior in situations involving the type of consequences that Skinner (1953) was interested in – those in which a single response produces both a reinforcing consequence (positive valence) and an aversive consequence (negative valence). In most of these experiments, the reinforcing consequence was food and the aversive consequence was electric shock, although one study used drugs as the consequences. Across these studies, there was interest in the extent to which the aversive consequence punished responding, which was demonstrated by increases in the latency to respond, decreases in the proportion of choice allocated to an alternative, or decreases in the value of the consequence associated with the aversive event. For example, Epstein (1984; Experiment 3) evaluated the temporal ordering of contingent deliveries of food and shock on pigeons' key pecking. Sessions took place in an operant conditioning chamber for pigeons with two response keys. Each session consisted of trials with two parts. In the first part, the left key was lit and the first response after 15 s elapsed completed the first requirement, which turned off the key and started the second part. In the second part, the right key was lit and the first response after 15 s completed the second requirement, turned off the key, and produced 3-s access to food. In one condition, the food was the only consequence of completing the second requirement. In the other condition, the consequence was food followed immediately by shock (3.0 mA; 30-ms duration). When food was the only consequence, the mean latency for pigeons to complete the first requirement was 16 s. When the food was followed by shock, the mean latency was 111 s. The presentation of shock following food increased the mean latency to respond.

In a much earlier study, Mowrer and Ullman (1945) showed that rats' consummatory behavior was differentially affected by the delay to response-contingent shock. First, the rats

were trained to eat from the feeder promptly when a 3-s buzzer sounded and food was delivered. After training, the rats were arranged into three groups and each rat was exposed to trials in which a shock contingency was added. If the rat ate the food during the buzzer, then a shock (0.06 mA, 2-s duration) was delivered either immediately after the buzzer, 3 s after the buzzer, or 9 s after the buzzer, depending on the group. If the rat did not eat the food until the buzzer terminated, then no shock was presented. After nine sessions of training, rats in the group with no delay between the buzzer and shock waited until the buzzer terminated before eating the food in 85 percent of the trials, rats with a 3-s delay waited in 60 percent of trials, and rats with a 9-s delay waited in 27 percent of trials. Shock was most effective when delivered immediately, and weakened as a function of the delay.

Woolverton, Freeman, Meyerson, and Green's (2012) study extended Mowrer and Ullman's (1945) findings to a situation where a single choice produced both cocaine (a reinforcing stimulus) and histamine (an aversive stimulus). Monkeys pressed one of two levers to self-administer either cocaine (50 or 100 $\mu\text{g/kg/injection}$) followed by an injection of histamine (0.37–50 $\mu\text{g/kg/injection}$) delivered immediately or cocaine followed by histamine delivered after a delay (1, 10, 30, 60, 180, 360, or 720 s). When the histamine was delayed by a short period (1-30 s), the monkeys chose the two consequences equally often. As the delay to histamine was raised beyond 30 s, preference for the cocaine with delayed histamine increased, and it was chosen nearly exclusively by all monkeys at long delays (360-720 s). This indicated that the effects of histamine were weakened as a function of its delay.

Two recent experiments have examined choice between a small food reinforcer and a large food reinforcer followed by delayed shock by pressing one of two response levers. In one experiment, Rodriguez, Bouzas, and Orduña (2017) divided sessions into five blocks of eight

trials each: Two forced-choice trials and six free-choice trials. In these trials, pressing one lever produced a single-valence consequence: A single food pellet. Pressing the other lever produced a dual-valence consequence: four food pellets and a shock (0.35-1.0 mA, 1000-ms duration) delayed by 0, 5, 10, 20, or 40 s. The five blocks of each session were associated with a different delay to shock. Across two conditions, it either increased from 0 to 40 s or decreased from 40 to 0 s. The proportion of trials in which each rat selected the single-valence consequence was recorded across in blocks of trials until choice was judged stable from session-to session. Then, the mean proportion was calculated from each block during the final three sessions of each condition. When the shock followed the press immediately, rats chose the single-valence consequence almost exclusively. The proportion of choices of the single-valence consequence generally decreased as a function of the delay to shock programmed in the block of trials. These results indicate that the delayed shock was aversive because it reduced choice of the larger reinforcer and that the delay weakened the effects of shock. They also fit Mazur's (1987) discounting function to the proportion choice of the single-valence consequence for individual rats and to the group results. They found that the function was generally a good fit for both individual (VAC: 64-98%) and group results (VAC: 81-89%).

Dumas (2014) developed a method based on Mazur's (1987) adjusting-delay procedure to study how the intensity (mA) and duration (ms) of delayed shock devalue a large-magnitude reinforcer. Rats chose between the two consequences by pressing two levers: a *single-valence lever* and a *dual-valence lever*. Pressing the single-valence lever produced one food pellet and pressing the dual-valence lever produced two or three food pellets and a shock delivered after an adjusting delay. The intensity (0.05-0.8 mA) and duration (100 or 200 ms) of the shock were manipulated across conditions. Sessions lasted for 16 blocks with four trials in each. The first

two trials were forced-choice trials, which ensured that each rat was exposed to the consequences associated with each lever. In a forced-choice trial, only one lever was inserted into the chamber, and a press produced the consequence normally associated with it. The rat was then exposed to a pair of free-choice trials in which both levers were inserted and the rat could choose between them.

Results of the free-choice trials led to adjustments in the delay to shock in the next block of trials. If the rat pressed the single-valence lever both times, the delay to shock was raised by 2 s in the next block of trials. If the rat pressed the dual-valence lever both times, the delay to shock was reduced by 2 s. If the rat pressed each lever once, the delay remained unchanged. As in Mazur's (1987) procedure, adjustments in the delay continued until the rat reliably chose the levers equally often, thus producing stability in the adjusting delay to shock. The adjusting delays during periods of stability were used in the calculation of indifference points. These indifference points indicated the delay at which the shock devalued the two or three food pellets of the dual-valence consequence such that they were equal in value to the one pellet of the single-valence consequence.

Figure 2 shows indifference points from a representative rat (AD5) in Dumas's (2014) study across a set of conditions with 200-ms shock durations. At shock intensities of 0.4 mA and 0.6 mA, indifference points stabilized at 4 s, indicating that the large reinforcer was not devalued by these shocks. The 0.8-mA shock produced an indifference point of 16 s, indicating that the large reinforcer followed after 16 s by a 0.8-mA shock that lasted 200 ms reduced the value of the additional food pellet such that it was equivalent in value to the single food pellet. When 0.8-mA shocks were delivered following the large reinforcer in an earlier condition in which shocks

Figure 2. Indifference points for AD5 in the final condition at each shock intensity with a 200-ms duration. Redrawn results from Dumas (2014).

lasted for 100 ms, the shock did not devalue the large reinforcer. Dumas (2014) showed how delayed shock devalued the large reinforcer as a function of shock intensity and duration.

Together, the small number of experiments conducted in the conflicting-consequences paradigm of self-control have identified variables that influence effects of delayed aversive consequences. Epstein (1984) found that delayed shock can punish responding – shown by increased response latencies, and Mowrer and Ullman (1945) showed that these effects are weakened as a function of delay. Woolverton et al. (2012) and Rodriguez et al. (2017) demonstrated that aversive events (histamine injections or shocks) affect choice most when they follow reinforcers by a short delay, and that these effects are weakened as the delay is raised. Finally, Dumas (2014) showed that delayed shock devalues reinforcing consequences that it follows and that these effects change as a direct function of the intensity and duration of the delayed shock.

Effects of Signals on Delayed Consequences

Researchers have sought methods to reduce the degradation caused by delaying a consequence. One approach with a large body of research involves signaling the delayed event. Signaling procedures have been largely successful at attenuating effects of delay on reinforcers (Azzi, Fix, Keller, & Rocha e Silva, 1964; Lattal 1984; Richards 1981; see Lattal 1987 for a review). For example, in the experiment conducted by Lattal (1984; Experiment 2), pigeons' key pecking produced food delivered either immediately or after a signaled or unsignaled delay (20, 75, or 150 s). For pigeons exposed to the 20-s delays, response rates were highest when food was delivered immediately (46-59 responses per min), moderate when food was delayed and a signal was provided (30-49 responses per min) and lowest when food was delayed and no signal was provided (2-29 responses per min). Pigeons exposed to longer delays with and

without the signaling procedure showed similar results: The signaling procedure attenuated effects of the delay, thereby increasing the effects of the food reinforcer.

Delay has also been shown to weaken effects of aversive events (e.g., Baron, 1965; Camp, Raymond, & Church, 1967; Kamin, 1959) and there is evidence that signaling procedures can attenuate the effects of delay – thereby increasing effects of delayed aversive events (Bevan & Dukes, 1955; Byrne & Poling, 2017; Tedford, 1969; Trenholme & Baron, 1975; Vogel-Sprott, 1966). For example, Baron (1965) trained rats on a task in which they gained access to water by running down a straight alley to a goal box. The rats were then exposed to a test condition in which the water was unavailable in the goal box and instead, an electric shock (0.7 mA, 500-ms duration) was produced. Across groups, the shock was delivered after 0, 5, 10, 20, or 30 s. The rats ran fastest when there was no shock. Speed was reduced to the greatest extent when shock was delivered immediately upon entrance into the goal box, and speed generally decreased as a function of the delay to shock.

Trenholme and Baron (1975; Experiments 1 and 2) showed that effects of delay on aversive consequences could be attenuated through the use of a signaling procedure. College students pressed a key that produced a green light, indicating that five cents was earned. After training, key presses produced one of two consequences. In a random half of the trials, pressing the key produced the green light. In the other half, pressing produced a flash of red light, indicating that five cents was lost. In Experiment 1, the students were arranged into four groups that differed in the delay between the response and money-loss: 0, 10, 20, or 40 s. Figure 3 shows the mean latency to respond by each of the groups (filled circles) and the mean response latency during training when responding never produced the red light (dashed line). Response latencies were longest in the 0-s delay group, followed by the 10-s delay group; they were not

Figure 3. Mean response latencies of groups of college students across delays to money losses in conditions in which delayed money losses unsignaled (filled symbols; Experiment 1) and signaled (unfilled symbols; Experiment 2). The dashed line shows the mean response latencies during the unpunished baseline condition. Redrawn results from Trenholme and Baron (1975).

reliably affected in the 20-s or 40-s delay groups. The punishing effects of money-losses were an inverse function of the delay, replicating Baron's (1965) findings.

In Experiment 2, the delayed money-loss was signaled by presenting white noise for 1 s immediately following the response that produced the money-loss and again 1 s before the money-loss. In this experiment, effects of the delay were greatly reduced. Response latencies in the group in which signaled money-losses were delayed by 10 s approximated those found in Experiment 1 when money-losses occurred immediately. Although the response latencies in groups in which signaled money-losses occurred after the 20 or 40 s were lower than those in the 10-s delay group, the response latencies were higher than those found in groups with equivalent delays to unsignaled money-losses. The signaling procedure allowed a delayed aversive event that did not affect behavior reliably when unsignaled to punish behavior when it was signaled. Together, these results show that delay weakens effects of an aversive consequence and that signaling the aversive consequence attenuates this effect.

Unpublished work from our laboratory investigated effects of signaling delayed shock on the same type of choices investigated in Dumas's (2014) thesis. Rats were exposed to a series of conditions that differed based on the (a) intensity and duration of shock in the dual-valence consequence and (b) whether a signal was provided for the delayed shock. In conditions with no signal, sessions took place as described in Dumas's experiment. In conditions with the signal, the houselight flashed between the response and the shock. The same adjusting-delay procedure used in Dumas's (2014) thesis was used to adjust the delay to shock and identify indifference points.

Figure 4 shows indifference points (s) for a representative rat as a function of the intensity of a 200-ms shock, without (filled symbols) and with (unfilled symbols) the signal. The

Figure 4. Indifference points for AD5 as a function of shock intensity in conditions without (filled circles) and with (unfilled circles) a signal for delayed shock. Results from unpublished work in our laboratory.

results generally replicated the results of Dumas's (2014) thesis: The intensity of shock had a direct effect on the value of the indifference points. The signal, however, did not affect indifference points systematically. It is unclear why this signaling procedure did not affect indifference points systematically. One possibility is that the signal might have been ineffective because of sensory properties of the stimulus used as the signal: the flashing houselight.

Although Sprague-Dawley rats (the strain used in this experiment) have poor visual acuity (e.g., Prusky, Harker, Douglas, & Whishaw, 2002), this possibility seems unlikely because a flashing houselight has been established as an effective signal in previous work (e.g., Perone & Galizio, 1987). A second possibility is that the signal was ineffective because the relation in the timing of the signal and the delayed shock was inconsistent. In the experiments in which signals increased the effects of delay on aversive consequences, the relation between the timing of the signal and the delayed punisher was held constant within each condition. In this experiment however, the duration of the signal varied across blocks of sessions in each condition based on changes in the delay to shock; therefore, the timing was inconsistent.

Statement of the Problem

Skinner's conceptualization of self-control was concerned with choice in relation to conflicting consequences. For Skinner, self-control was a problem when a single choice produced both immediate reinforcers and delayed aversive events. Recent research (Dumas, 2014; Rodriguez et al., 2017) investigating this type of situation has provided rats with choice between either a small reinforcer delivered immediately or a large reinforcer delivered immediately and followed by delayed shock. In the experiment that examined how delayed shock devalues a large reinforcer (Dumas, 2014), adjustments in the delay to shock were made

until the large reinforcer was equal in value to the small reinforcer. The present experiments were designed to expand upon this small base.

In present experiments, rats were exposed to choices between (a) food delivered immediately and followed by a delayed shock or (b) the same amount of food after a delay. Whereas Dumas's (2014) procedure adjusted the delay to shock, the procedure used in the present experiments held the delay to shock constant in each condition and adjusted the delay to food until an indifference point was determined. Experiment 1 was designed to explore how the value of a dual-valence consequence changes as a function of the delay between the reinforcing and aversive parts of the consequence. Within each condition, rats chose between two pellets of food delivered immediately followed by a delayed shock (0.8 mA, 200-ms duration) versus two pellets of food delivered after an adjusting delay. The delay to food was adjusted across blocks of trials until an indifference point was determined in each condition. Across conditions, the delay to shock was manipulated (1, 2, 4, 8, 16, 32, or 64 s). Experiment 2 evaluated how the effects of delay are influenced by signaling the delayed shock (0.8 mA, 200-ms duration). As in Experiment 1, the delay to food was adjusted until an indifference point was identified in each condition. Across conditions, either the delay to shock or the presence of a signal for delayed shock was manipulated. Indifference points were identified in Signal and No-Signal conditions at each delay.

General Method

Experiments 1 and 2 had a number of elements in common, including the treatment of the rats, the apparatus, the preliminary training used to establish lever-pressing, and the adjusting-delay procedure. The following sections describe these shared elements.

Subjects

Eight experimentally naive, male Sprague Dawley rats were studied (four per experiment). The rats were 77 days old at the start of the experiment. They were maintained at 80 percent ($\pm 2\%$) of their free-feeding body weights by food reinforcers delivered during the experimental sessions and supplemental feedings of standard lab chow in the home cage at least 30 min after the sessions. Target weights were adjusted periodically according to growth charts based on curves provided by the supplier. For an example of the growth chart, see Appendix A. The rats were housed in pairs in a temperature-controlled room with a 12:12 hr reversed light/dark cycle and water was freely available in the home cages. The treatment of the rats, in and out of the experimental sessions, complied with a protocol approved by the West Virginia University Animal Care and Use Committee.

Apparatus

Sessions were conducted in four operant-conditioning chambers enclosed in ventilated sound-attenuating chests (Med Associates Inc., St. Albans, VT). The interior of each chamber was 29 cm long, 22 cm high, and 24 cm deep. The ceiling and sidewalls were constructed of Plexiglas, and the end walls of stainless steel. The floor consisted of 19 stainless-steel rods 0.5 cm in diameter, spaced approximately 1.3 cm apart. On the front wall were two retractable levers. Each lever was 4.4 cm wide, 1.3 cm thick, and protruded 1.9 cm into the chamber when inserted. The inside edges of the levers were spaced 11.4 cm apart (5.7 cm from the middle of the wall). The tops of the levers were positioned 8 cm from the floor. White cue lights (No. 1820 bulb) were located approximately 5 cm above each lever, but were not used in the experiments. An audio speaker was located behind the back wall. Grain-based food pellets (45-mg, BioServ) could be delivered into a feeder centered on the front wall. Each pellet was

accompanied by a 1000-Hz tone lasting 1 s. Multiple pellets were delivered by operating the feeder multiple times, each separated by 50 ms. When multiple pellets were delivered, the accompanying tone lasted an equivalent number of seconds as the number of pellets delivered (e.g., two pellets were accompanied by a 2-s tone). If pellet delivery was contingent upon a lever press (all sessions except the first session of preliminary training), the levers were retracted for the duration of the tone. Aversive stimulation consisted of scrambled foot shock controlled by a constant-current shock generator (Med Associates ENV-413). General illumination was provided by a houselight (No. 1820 bulb) located on the back wall. White noise (80 dB) masked extraneous sounds. Experimental events were controlled and recorded with computers running programs written in Visual Basic 2010. Computers were connected to the chambers via digital interfaces (Measurement Computing, model PCI-PDIS08).

Preliminary Training

Each rat received training to establish the delivery of a food pellet as a reinforcer and to engender responding on both levers. Throughout training, the houselight illuminated the chamber and white noise was played through the speaker except when a pellet delivery was underway, at which time a 1000-Hz tone replaced the white noise. The first session began with the delivery of three pellets. After these were consumed, individual pellets were delivered manually after progressively increasing intervals. The session was considered complete when the rat reliably consumed each pellet within 3 s of delivery, with at least 60 s separating deliveries, and with the rat's head an estimated 3 in away from the feeder at the time of delivery.

Lever-press training sessions began with the presentation of one lever. Each press produced a food pellet. This continued until 10 pellets were delivered, after which the first lever was retracted and the other lever was inserted, and the same fixed-ratio (FR 1) reinforcement

schedule was in effect until 10 pellets were delivered. The FR 1 schedule was alternated between the levers in blocks of five pellets until 100 pellets were delivered or until 1 hr elapsed. Reliable responding was established on both levers in a single session.

Adjusting-Delay Procedure

In both experiments, the same adjusting-delay procedure was used to identify the time at which delayed food was chosen at the same rate as immediate food followed by delayed shock. Each rat was presented with two response alternatives. A single press on the *dual-valence* lever produced two food pellets (positive valence) immediately and a shock (negative valence) which was delivered after a fixed delay. The fixed delay to shock was held constant within each condition, but varied across conditions. A single press on the *single-valence* lever produced two food pellets (positive valence) after a delay that was adjusted, across blocks of trials, based on the rat's choice. At the start of each condition, the adjusting delay to food was 0 s. The delay was adjusted across blocks of trials and sessions as described below.

Sessions were normally conducted 7 days per week at approximately the same time each day. Sessions began with a 5-min blackout period during which the chamber was dark and silent and the levers were retracted. This allowed the rats to recover from transportation from the vivarium and handling. After the blackout, the houselight and white noise were turned on and blocks of trials began. Each block consisted of four trials: two forced-choice trials followed by two free-choice trials (described below). Sessions ended after 16 blocks or 300 min, whichever occurred first.

Forced-choice trials. The pair of forced-choice trials that began each block ensured that the rat had recent exposure to the consequences of pressing both levers before the free-choice trials took place. In the first forced-choice trial, one lever was inserted into the chamber. After a

press, the lever was retracted and the consequence associated with that lever was delivered. In the second forced-choice trial, the other lever was inserted and a press produced the consequence associated with it. The first block of trials in a session always began with a forced-single-valence trial. This allowed trial yoking to occur, when necessary, following the first trial. Trial yoking is described in the “trial-durations” subsection below. With the exception of the first block, the lever presented in the first forced-choice trial of a block was decided randomly in every odd-numbered block. Even-numbered blocks began with the lever presented second in the previous odd-numbered block.

Free-choice trials. The second pair of trials in a block were free-choice trials with both levers inserted. When one lever was pressed, both levers were retracted and the consequence associated with the pressed lever was delivered. As in Mazur’s (1987) procedure, response allocation during the free-choice trials determined adjustments in the delay to food on the single-valence lever in the subsequent block. If the single-valence lever was pressed in both free-choice trials, the adjusting delay to food was *raised* by 2 s in the next block. If the dual-valence lever was pressed in both trials, the adjusting delay was *reduced* by 2 s in the next block. If each lever was pressed once, the adjusting delay remained unchanged.

Trial durations. Trials were programmed to start every 90 s, with the constraint that a minimum of 15 s separated the delivery of a consequence (food or shock) from the start of the next trial. The 15-s rule avoided pairing a consequence of responding with the onset of the next trial. A trial-yoking procedure was implemented to prevent trial duration from differing between trial types. When a single-valence trial lasted longer than 90 s, the subsequent dual-valence trial duration was yoked to this trial duration. A new yoked duration was established whenever a new single-valence trial exceeded 90 s.

Stability Criteria

Within each condition, adjustments in the delay to food continued across blocks and sessions until the rat's choices were indifferent between the single-valence and dual-valence consequences. To identify this indifference point in each condition, adjusting delays were examined in each half-session (8 blocks). Choice was considered stable when the following criteria were satisfied. (a) The mean delay to food in each of the last six half-sessions could not be the highest nor lowest half-session mean in the condition. (b) The mean of all adjusting delays to food aggregated over the last six half-sessions could be neither the highest nor the lowest of the condition. (c) The mean of all adjusting delays to food aggregated over the last six half-sessions could not differ from the mean adjusting delay aggregated over the preceding six half-sessions by more than 10 percent or by more than 1 s (whichever is larger). (d) For at least five of the six sessions, choice for either alternative could not occur less than 10 or more than 22 times (of the 32 free-choice trials per session). This range was chosen based on probabilities obtained from the binomial distribution. Across 32 choices, if responding were truly indifferent – that is, if the probability of responding on either lever was .5 – the probability of either alternative being chosen less than 10 times or more than 22 times is .01. This probability was seen as sufficiently extreme to reject the null hypothesis of indifference. The only exception to the above requirement was if an indifference point was reached in the range of 0 to 2 s due to the floor effect created by the minimum possible delay of 0 s. (e) The proportion of free-choice responses for either alternative across the stable sessions could not form a monotonic trend. (f) All trials must have been completed in every session. When the stability criteria were satisfied, the mean adjusting delay of the last 12 half-sessions was the measured indifference point.

Experiment 1

The purpose of Experiment 1 was to examine how the value of a dual-valence consequence changes as a function of the delay between an immediate reinforcer and a delayed aversive consequence. Rats chose between two consequences – one of which produced delayed food (the single-valence consequence) and the other produced immediate food plus delayed shock (the dual-valence consequence). Of interest in this experiment was how the delayed shock affected the value of a dual-valence consequence as the delay to shock was manipulated.

Method

Four rats (FD1, FD3, FD4, and FD9) were used in Experiment 1. In each condition, the rat chose between (a) delayed food by pressing the single-valence lever and (b) immediate food and a delayed shock by pressing the dual-valence lever. On the single-valence lever, the delay to food was 0 s at the beginning of each condition and was adjusted until choice was judged stable as described in the general method section. Across six conditions, the delay to shock was manipulated in the following order: 64 s, 32 s, 16 s, 8 s, 4 s, and 2 s. Two rats (FD1 and FD4) also were exposed to a condition with a 1-s delay to shock. Then all rats were exposed to replications of selected conditions. The conditions for each rat are shown in Table 1, along with the number of sessions per condition.

Results

Indifference Points

The main results of interest are the indifference points, calculated as the mean of the 96 adjusting delays aggregated over the six stable sessions in each condition. Figure 5 shows indifference points as a function of the delay to shock for individual rats as well as group means. Table 1 shows the same information with numerical accuracy. Symbols represent the

Table 1

Experiment 1. Conditions based on the fixed delay to shock (s) for each rat (FD1-FD9). Order of conditions, indifference points (s), and the total number of sessions per condition also are shown.

Fixed Delay to Shock (s) Order		FD1		FD3		FD4		FD9		Group
		Indifference Points (s)	Ses- sions	Indifference Points (s)	Ses- sions	Indifference Points (s)	Ses- sions	Indifference Points (s)	Ses- sions	Indifference Points (s)
Initial Conditions										
1		4.5	31			22.0	12			13.3
2	6	13.5	25	26.7	13	8.8	11	73.0	32	30.5
4	5	13.6	30	22.5	22	5.9	11	19.9	31	15.5
8	4	5.6	8	10.5	16	3.2	15	11.6	16	7.8
16	3	10.5	8	0.5	8	2.3	8	17.1	13	7.6
32	2	0.3	8	0.2	9	1.6	8	6.5	22	2.2
64	1	0.5	13	0.0	12	0.7	13	15.8	61	4.3
Replicated Conditions										
1		7.3	13			10.6	9			8.9
2		5.2	13	29.3	19	6.6	12	94.9	10	34.0
4				24.8	10	7.9	25			16.3
16		2.0	8	14.5	22	14.7	25	8.1	22	9.2
16						6.8	23			
32				6.2	18					6.2
64		4.0	8	6.1	10	5.3	10	3.6	10	4.8

Note. Rats were exposed to conditions in the same order for the first six conditions (delays of 2 to 64 s). Then, rats were exposed to conditions with new delays to shock (s) and replications in the following order: FD1 = 1, 16, 2, 64, and 1; FD3 = 16, 32, 64, 2, and 4; FD4 = 1, 16, 64, 2, 4, 1, and 16; FD9 = 64, 16, and 2.

Figure 5. *Experiment 1:* Indifference points (s) in initial (left, circles) and replicated (middle, squares) conditions, and in both conditions combined (right) for individual rats (top four panels) and the mean indifference points averaged across rats (bottom panels). Curves show the best-fitting hyperbolic function fit to indifference points in initial (solid) and replicated (dashed) conditions. *Note.* The scale on the y-axis is changed for FD9 to account for long indifference points.

indifference points during the initial exposure to conditions (left column), replicated conditions (middle column), and in both sets of conditions combined (right column). Circles show results for the initial exposure to a condition and squares show results for replicated conditions. The lines show the best-fitting hyperbola based on Mazur's (1987) discounting function for the initial (solid) and replicated (dashed) conditions.

The indifference points identified in each condition show the extent to which the delayed shock devalued the immediate food. For example, for FD3, shock delayed by 2 s devalued the immediate food to the point that it was equivalent to food delayed by 27 s. The effects of shock on the value of the dual-valence consequence changed as an inverse function of the delay to shock. In most cases, shock exerted its maximum effects on the value of the dual-valence consequence during the condition with the shortest delay to shock (range: 4.5-94.9 s; 1-s or 2-s delay, depending on the rat). As the delay to shock was raised to intermediate values (8-16 s), effects of shock on the value of the dual-valence consequence were generally reduced, producing intermediate indifference points (range: 0.5-17.1 s). When the delay to shock was at least 32 s, the effects of shock were extremely weak, producing short indifference points (range: 0.0-6.5 s). In fact, when three of the rats (FD1, FD3, and FD4) initially were exposed to shocks delayed by 32 and 64 s, the adjusting delay stabilized between 2 s and the 0-s minimum – indicating that such long-delayed shock had almost no effect on choice. In most replications, indifference points were similar to those produced in the initial conditions. The notable exception occurred during a replication the 16-s delay to shock for FD4, in which the indifference point was much longer than in the initial condition (14.7 s vs 2.3 s). The order of conditions may have affected the indifference point in this replicated condition, which followed immediately after the 1-s delay that produced the longest indifference point for FD4. When the 16-s delay to shock was

replicated again following a condition during which the effects of shock were weaker (10.6 s; 1-s delay), the indifference point was shorter (6.8 s) and more closely approximated the indifference point in the initial condition.

Table 2 shows the parameters of the best-fitting hyperbola based on Mazur's function and the variance in the indifference points accounted for (VAC) by the function. The function describes the data with mixed success. The function fit the individual results well for three rats during the initial conditions (FD3, FD4, and FD9; VAC: 87-98%) and for FD3 and FD9 during the replicated conditions (VAC: 98-100%); however, the function described results poorly for FD4 in the replicated conditions (VAC: 0%) and for FD1 in both sets of conditions (VAC: 17-35%). Mazur's function also described the group results with mixed results. Because only two rats (FD1 and FD4) were exposed to the 1-s delay to shock, Mazur's function was fit to the group data both with and without the results from the 1-s delay condition. The function described the results poorly in the initial and replicated sets of conditions when the 1-s delay was included (VAC: 0-35%); however, when the function is fit to data from conditions to which all rats were exposed, the function described the results well (VAC: 91-96%).

The parameters reported in Table 2 describe the maximum effect of delayed shock (M) across sets of conditions for each rat and the rate at which the effects of shock were degraded by delay (k) as estimated by Mazur's (1987) discounting function. Comparisons of M across series show the extent to which the maximum effect of shock was replicated across initial and replicated sets of conditions. For one rat (FD3), M was similar across sets of conditions (within 3 s). For FD1 and FD4, the maximum effects of shock were lower during replicated conditions (differences of 6.3 s and 7.3 s), and for FD9, the maximum effects of shock were higher in the replicated set of conditions (difference of 21.9 s). The parameter k describes how steeply the

Table 2

Experiment 1. Parameters (M and k) for the best-fitting hyperbola based on Mazur's equation in the initial (Series 1) and replicated (Series 2) sets of conditions for each rat and for the group of rats. The number of indifference points to which Mazur's function was fit is represented by N. VAC is the variance in the indifference points accounted for by the best-fitting hyperbola. Because only two rats (FD1 and FD4) were exposed to the 1-s delay to shock, the group means are presented both with (1-64 s) and without (2-64 s) the 1-s delay condition.

Rat	Series	N	M	k	VAC
FD1	1	7	13.6	0.08	30
	2	4	7.3	0.09	17
FD3	1	6	26.7	0.27	91
	2	5	29.3	0.08	98
FD4	1	7	22.0	1.17	98
	2	6	14.7	0.04	0
FD9	1	6	73.0	0.94	87
	2	3	94.9	0.72	100
Mean (1-64 s)	1	7	30.5	0.25	35
	2	6	34.0	0.19	0
Mean (2-64 s)	1	6	30.5	0.41	96
	2	5	34.0	0.34	91

Note. Mazur's equation is $V = M / (1 + k D)$ where V represents the predicted adjusted delay to food at a given fixed delay to shock, M represents the maximum adjusted delay to food, D represents a given fixed delay to shock, and k represents the rate at which the effects of delayed shock are degraded per second that the shock is delayed.

effects of shock were degraded per s by which the shock was delayed. In some cases, k was high – as shown in the initial sets of conditions for FD4 and FD9 and in the set of replicated conditions for FD9 (range: 0.72-1.17). These high k -values describe a keen sensitivity to delay – the effects of shock decreased rapidly from the condition in which the maximum effects of shock were produced to when shock was delayed by an additional 1 or 2 s. In most other sets of conditions, k values were lower (range: 0.04-0.27) – indicating that shocks effects decayed more gradually as a function of delay. With the exception of FD1, k values identified across sets of conditions were not replicated within rats – indicating that rate by which the effects of shock were degraded by delay was not static across sets of conditions for most rats (differences ranged from 0.01-1.13).

Adjusting Delays across Blocks of Trials

The summary in Figure 5 shows the stable adjusting delay to food at the end of each condition, that is, the indifference points. Figure 6 shows the adjusting delay to food throughout each condition. This block-by-block analysis provides information about the pattern of adjustments made before choice stabilized. Conditions are shown in the order in which each rat was exposed to them. Each increase in adjusting delay indicates that two consecutive free choices of the single-valence (delayed food) consequence occurred in the prior block; a decrease indicates two choices of the dual-valence consequence (immediate food + delayed shock); no change indicates one choice of each option. Arrows extending from the x-axis mark the beginning of periods of stability in each condition and phase lines mark changes in conditions.

Figure 6 shows that the delays to food were not always adjusted immediately to the ultimate value. Rather, some conditions are characterized by one or more prominent peaks in delays which surpass the stable delay (e.g., the first condition for all rats; initial 2-s condition for

Figure 6. *Experiment 1:* Adjusting delay to food (s) plotted across successive blocks of trials. Phase lines indicate changes in conditions and arrows extending from the x-axis mark the starting point of the 96 blocks in which responding was judged stable. Phase labels show the fixed delay to shock (s) in each condition.

FD1). These peaks show that choice was allocated to the single-valence lever for an extended period leading up to the peak, and then to the dual-valence lever following the peak. Similar peaks and reversals were reported by Dumas (2014) and show that indifference is often preceded by periods of near exclusive choice for the single-valence lever, followed by a reversal in choice in which the dual-valence lever is chosen nearly exclusively.

Response Latencies in Forced-Choice Trials

Response latencies provide a measure of the strength of responding maintained by the consequences associated with the two levers (Mackintosh, 1974, pp. 143-144). Consequences that function as effective reinforcers maintain strong responding characterized by relatively short latencies, whereas reinforcers that are less effective maintain weaker responding characterized by relatively long response latencies. In the present experiment, the adjusting-delay procedure identified the point at which food delayed by a given period was equivalent to food delivered immediately followed by a delayed shock. If it is the case that the consequences produced by the two levers are truly equivalent during the stable sessions in each condition, then the latency to respond on the two levers should be approximately equal.

To address these issues, Figure 7 shows the median (and interquartile range) of the response latencies during the forced-choice trials in the stable sessions of each condition. The latencies to respond on the single-valence lever are shown by unfilled bars and latencies for the dual-valence lever are shown by shaded bars. Error bars extend from the 25th to the 75th percentiles. Differences in the latency to respond on the single-valence and dual-valence levers were idiosyncratic across rats. For two rats (FD1 and FD4), the latencies were not systematically different: In most cases, the median single-valence and dual-valence latencies were similar and there was a high degree of overlap in the interquartile ranges. For the other two rats (FD3 and

Figure 7. *Experiment 1:* Latency to respond (s) during forced-choice trials in stable sessions of each condition, shown in the relative order of exposure for each rat. Bars show the median latency during forced-single-valence trials (unfilled) and forced-dual-valence trials (shaded). Error bars extend from the 25th to 75th percentiles.

FD9), the latencies to respond on the single-valence and dual-valence levers differed in several of the conditions – indicating that, for these rats, latencies might have been differentially affected by the consequences associated with the two levers during stable sessions.

To quantify the analysis of the response latencies, sign tests were conducted on pairs of forced-choice trials in the blocks stable sessions of each condition (see Siegel, 1956 for a description of the sign test). Table 3 shows the results displayed in Figure 7 with numerical accuracy, along with the results of sign tests. Consistent with the results shown in Figure 7, latencies to respond on the single-valence and dual-valence levers, in most cases (17 of 24; 70%) comparisons were not significantly different for FD1 and FD4 as judged by the sign test. For FD3 and FD9 however, significant differences in response latencies were found in 17 of 20 comparisons (85%). In most of these cases, (15 of 17; 88%) response latencies were longer on the single-valence lever than on the dual-valence lever. This finding suggests that the reinforcing function of the consequences associated with the two levers were not always equivalent, even though choice between the consequences was indifferent. It appears that in some cases, the latency to respond may have been under the control of the immediate reinforcing consequence of pressing each lever. Whereas the dual-valence lever produced food immediately every time it was pressed, the single-valence lever often produced food only after some delay. This assertion is supported by the fact that the two rats that most frequently produced significantly longer latencies in single-valence trials (FD3 and FD9) also produced the longest indifference points.

To determine the relation between latency to respond in single-valence and dual-valence trials and the delay to food, the response latencies were plotted as a function of the adjusting delays in stable sessions of each condition (indifference points). The top panels in Figure 8

Table 3

Experiment 1. Forced-choice latency data (25th, 50th, 75th percentile) and results of sign tests from the 96 stable blocks of initial and replicated conditions for each rat. Plus and minus signs were calculated by subtracting the forced-dual-valence latency from the forced-single-valence latency, and the right-most column shows comparisons that were significant at the .05, .01, and .001 levels. Missing p-values indicate that the test results were not significant at $p < .05$. Plus signs indicate comparisons with a longer latency to respond during single-valence trials and minus signs indicate a longer latency to respond during dual-valence trials.

Rat	Fixed Delay to Shock (s)	Single-Valence			Dual-Valence			Sign Test		
		25th	50th	75th	25th	50th	75th	+	-	$p <$
FD1	1	0.6	0.8	1.0	0.6	0.7	1.2	44	52	--
	1	0.7	1.0	1.3	0.7	1.0	1.2	55	41	--
	2	0.9	1.5	2.2	0.7	0.9	1.6	60	36	.05
	2	0.6	0.8	1.1	0.6	0.8	1.2	49	46	--
	4	0.7	0.9	1.3	0.7	1.0	1.8	45	51	--
	8	0.6	0.7	1.1	0.6	0.8	1.5	52	44	--
	16	0.7	0.8	1.3	0.7	0.9	1.4	47	48	--
	16	0.6	0.7	1.0	0.6	0.9	1.3	43	53	--
	32	0.7	0.9	1.4	0.7	0.7	1.4	40	55	--
	64	0.7	0.8	1.6	0.7	0.7	1.1	36	57	.05
FD3	64	0.7	0.9	1.2	0.7	1.0	1.2	40	54	--
	2	1.3	1.6	2.1	0.6	1.0	1.5	70	26	.001
	2	1.4	1.8	2.7	1.2	2.2	10.1	39	57	--
	4	1.2	1.6	1.9	0.6	0.8	1.2	74	21	.001
	4	1.3	1.6	2.0	1.3	1.7	2.0	44	52	--
	8	0.7	0.8	1.6	0.5	0.7	0.9	67	26	.001
	16	0.7	1.0	1.3	0.5	0.6	1.3	61	34	.01
	16	1.0	1.3	1.7	0.6	0.7	0.9	76	20	.001
	32	0.8	1.0	1.2	0.5	0.6	0.7	80	14	.001
	32	0.6	0.8	1.2	0.5	0.6	0.9	70	26	.001
FD4	64	0.9	1.1	1.4	0.5	0.6	0.7	81	15	.001
	64	0.7	1.0	1.3	0.6	0.7	1.0	66	28	.001
	1	0.7	0.9	1.2	0.6	0.8	1.5	53	42	--
	1	0.8	1.0	1.4	0.6	0.7	0.9	71	25	.001
	2	0.6	0.8	1.1	0.6	0.6	0.9	66	30	.001
	2	0.7	0.8	1.1	0.6	0.7	1.0	52	42	--
	4	0.5	0.7	0.9	0.5	0.7	1.5	38	58	--
	4	0.8	1.0	1.3	0.6	0.7	0.9	77	19	.001
	8	0.6	0.7	0.9	0.5	0.6	0.9	52	43	--
	16	0.5	0.6	0.8	0.6	0.6	0.9	42	53	--
FD9	16	0.7	0.9	1.0	0.6	0.7	1.0	55	40	--
	16	0.9	1.0	1.2	0.6	0.7	0.8	82	14	.001
	32	0.6	0.7	0.9	0.6	0.6	1.0	47	49	--
	64	0.7	0.9	1.2	0.6	0.7	0.9	63	31	.05
	64	0.6	0.7	0.9	0.6	0.7	0.9	50	45	--
	2	3.2	5.1	7.6	2.8	22.5	98.1	28	68	.001
	2	2.6	4.6	13.7	1.4	16.3	77.6	36	60	.01
	4	1.0	1.2	1.4	0.7	0.8	1.0	79	17	.001
	8	1.1	1.3	1.6	0.7	1.0	1.4	74	21	.001
	16	1.1	1.4	1.7	0.8	1.0	1.2	77	18	.001
FD9	16	1.0	1.3	1.7	0.9	1.3	1.9	53	43	--
	32	1.3	1.7	2.0	0.7	0.9	1.0	88	7	.001
	64	1.5	2.0	2.3	0.7	0.8	1.0	91	5	.001
	64	0.9	1.0	1.3	0.8	0.9	1.2	60	35	.01

Figure 8. *Experiment 1:* The latency to respond (s) during forced-single-valence (top panels) and dual-valence (bottom panels) trials plotted as a function of the indifference point (s) identified in each condition. Symbols show the median of the 96 latencies aggregated over the stable sessions in each condition and the dashed line shows the best-fitting linear function. The tables in the middle-right and bottom right panels of the figure shows the slope of the best-fitting linear function and the correlation (Pearson's r).

show, for each rat, the median latency to respond (s) during forced-single-valence trials plotted as a function of the indifference point (s) identified in each condition. The dashed line shows the best-fitting linear function. The slope of the function and the correlation between the median latency and the indifference point (Pearson's r) is reported in the table located in the middle-right panel of the figure. For every rat, the relation between single-valence response latencies and the adjusting delay during stable sessions was positive ($r = .60$ to $.95$). In other words, the latency to respond on the single-valence lever was directly related to the delay to the food following a response on that lever. For completeness, the relation between dual-valence response latencies and indifference points were also analyzed (bottom panels of Figure 8). The correlations (shown in the bottom-right panel) were idiosyncratic across rats ($r = -.44$ to $.44$). For FD4 and FD9, the correlation was positive and for FD1 and FD3, it was negative.

Taken together, these results provide evidence that, although choice between single-valence and dual-valence consequences was affected by the delayed shock, response latencies were under the control of the reinforcing consequences associated with the levers. Food was produced immediately following each response on the dual-valence lever and strong responding was maintained on this lever – as evidenced by short response latencies in most cases, independent of the delay to food at each indifference point. In contrast, the reinforcing consequence resulting from a press on the single-valence lever was often delayed – sometimes by long periods. The latency analysis showed that the strength of responding on the single-valence lever was inversely related to the delay to food at each indifference point. Generally, the longer the delay to food produced by a response on the single-valence lever, the weaker responding on the single-valence lever, shown by longer latencies to respond.

Experiment 2

Experiment 1 examined how the value of a dual-valence consequence (immediate food with delayed shock) changes as a function of the delay to the aversive consequence. The purpose of Experiment 2 was to evaluate whether effects of delayed shock could be influenced through the use of a signaling procedure.

Method

Four different rats (FD5, FD6, FD7, and FD8) from those used in Experiment 1 were used in Experiment 2. In each condition, each rat was exposed to choices between (a) food delivered after an adjusting delay and (b) food delivered immediately plus a shock delivered after a fixed delay. The adjusting delay to food following a response on the single-valence lever started at 0 s in the beginning of each condition and was adjusted within the condition until choice was judged stable as described in the general method section. Across conditions, one of two variables were manipulated: (a) the fixed delay to shock following a press on the dual-valence lever or (b) the presence of a signal of delayed shock.

The signaling arrangement used in Signal conditions of Experiment 2 was modeled after the procedure used in Trenholme and Baron's (1975) Experiment 2. This procedure ensured a consistent relation between the timing of the signal and the delayed shock across conditions with different delays to shock. Figure 9 is a diagram of the period following a response on the dual-valence lever in a condition without (left panel) or with (right panel) the signal. During Signal conditions, the signal was presented for 2 s following the food reinforcer and for 2 s before the shock. In conditions in which shock was delayed by only 2 or 4 seconds, the signal lasted for the entire fixed delay to shock. In other conditions, a gap (4-60 s) separated the 2-s segments of the signal. The signal consisted of pulsing the houselight and white noise off and on according to a cycle that repeated twice per second (250-ms off, 250-ms on). During No-Signal conditions, the

Figure 9. Illustration of delayed shock without (left panel) or with (right panel) a signal delivered after each response on the dual-valence lever in Experiment 2.

events following a response on the dual-valence lever were identical to Experiment 1 – no additional stimuli were presented between the delivery of food and the shock.

Signal training. One additional session of preliminary training took place immediately before the start of the first condition. The goal of this training was to pair the signal with shock before the signal was delivered as a consequence of responding. Each rat was exposed to a single session in which the response levers were retracted and a procedure similar to Bouton and Bolles (1979, Experiment 1) was used. During the session, signal and shock presentations were arranged after intervals of 120 s, 180 s, or 240 s. When the interval elapsed, the signal was turned on for 2 s and followed immediately by a shock. The session lasted for 15 signal-shock presentations. Each of the three intervals was repeated at random without replacement. When all three intervals were used, a fresh set of selections without replacement was arranged.

Each rat in Experiment 2 was exposed to 11 conditions that differed either in the delay to shock programmed as part of the dual-valence consequence, or the presence of a signal for the delayed shock. All rats were exposed to conditions in the same order. Table 4 shows the order in which rats were exposed to conditions in Experiment 2, along with the indifference points (s) identified in each condition, and the number of sessions per condition.

Results

Indifference Points

As in Experiment 1, the main results of interest were indifference points, calculated as the mean of the 96 adjusting delays aggregated over the six stable sessions in each condition. Figure 10 shows indifference points for individual rats as well as group means and Table 4 shows the same information with numerical accuracy. Symbols represent the indifference points during

Table 4

Experiment 2. Conditions differed based on the fixed delay to shock (s) and the absence (No-Signal Conditions) or presence (Signal Conditions) of a signal for delayed shock for each rat (FD5-FD8). Indifference points (s) in each condition and the total number of sessions per condition are shown.

		FD5		FD6		FD7		FD8		Mean
Fixed Delay to Shock (s)	Order	Indifference Point (s)	Ses- sions	Indifference Point (s)	Ses- sions	Indifference Point (s)	Ses- sions	Indifference Point (s)	Ses- sions	Indifference Point (s)
No-Signal Conditions										
1	11	5.0	14	3.8	12	34.0	24	0.8	14	10.9
2	10	4.5	16	3.6	22	63.4	19	4.3	18	19.0
4	7	9.9	11	5.9	8	34.8	8	13.9	10	16.1
8	6	5.6	9	4.3	15	22.7	9	13.0	8	11.4
16	2	6.3	8	3.9	15	13.8	21	8.4	15	8.1
64	3	3.6	11	0.9	10	8.2	14	1.0	16	3.4
Signal Conditions										
2	9	5.0	11	9.8	10	28.7	51	12.6	8	14.0
4	8	6.9	21	4.3	14	30.9	13	16.8	9	14.7
8	5	10.8	8	6.6	12	18.2	9	12.8	10	12.1
16	1	7.8	19	7.1	24	4.5	21	12.0	16	7.8
64	4	4.1	9	0.5	16	5.9	16	3.5	15	3.5

Figure 10. *Experiment 2:* Indifference points in conditions without (left, filled) and with (middle, unfilled) signaled delayed shock, and in both sets of conditions combined (right) for individual rats (top panels) and the mean indifference points averaged across rats (bottom panels). Curves show Mazur's hyperbolic discounting function fit to indifference points of No-Signal (solid) and Signal (dashed) conditions. *Note.* The scale on the y-axis is changed for FD7 to account for long indifference points.

No-Signal conditions (left column), Signal conditions (middle column), and in both sets of conditions combined (right column). Filled symbols show results in No-Signal conditions and unfilled symbols show results in Signal conditions. The lines show the best-fitting hyperbola based on Mazur's (1987) function for the No-Signal (solid) and Signal (dashed) conditions.

Effects of delay. Changes in the indifference points across conditions show the extent to which the delayed shock devalued the immediate food. As in Experiment 1, delayed shock generally devalued food to the greatest extent at short delays and decreased systematically as the delay to shock was raised. This general effect occurred whether or not the delayed shock was signaled. Conditions with short delays to shock (1-4 s) normally produced long indifference points (range: 0.9-63.4 s), conditions with intermediate delays to shock (8-16 s) normally produced intermediate indifference points (range: 3.9-22.7 s), and conditions with a long delay to shock (64 s) normally produced the shortest indifference points (range: 0.5-8.2 s).

Mazur's discounting function fit the results with mixed success. Table 5 shows the number of indifference points (N) to which Mazur's function was fit, the parameters (M and k) of the best-fitting hyperbola, and the variance accounted for (VAC) by Mazur's function when it was fit to indifference points from the No-Signal and Signal conditions. The function fit the results well for FD7 in both sets of conditions (VAC: 84-98%). For the other three rats, the fit of the function was less reliable. For FD8, the function accounted for a high percent of the variance (76%) in Signal conditions and none of the variance in No-Signal conditions. For FD5 and FD6, the function fit the results of both sets of conditions poorly (VAC: 0-0% for FD5 and 27-49% for FD6 respectively). When Mazur's function was fit to the group results, the function accounted for a high percent of the variance in the results (96%) in Signal conditions and a low percent (56%) in No-Signal conditions.

The parameters reported in Table 5 show the maximum effect of delayed shock (M) and the rate at which effects of shock were degraded (k) in Signal and No-Signal conditions. For most rats (FD5, FD6, and FD8), maximum effects of shock were slightly higher in Signal conditions than in No-Signal conditions, but the differences were small (within 4 s). Similarly, these rats had k -values that were slightly higher in Signal conditions, but these differences were also small (within 0.03). Because both parameters of Mazur's function were replicated fairly closely, it suggests that the signaling procedure did not have a large effect on the effects of shock for these rats. For FD7 however, the maximum effect of shock was 32.5 s longer in the No-Signal condition than in the Signal condition. The difference in the k -value produced in Signal and No-Signal conditions was also greater for this rat than for the other three (difference of 0.09). These differences might be taken as evidence that the signaling procedure produced a large reduction in the effects of the shock, but considering the differences between M (range: 2.6-21.9 s) and k (range: 0.01-1.13) produced across replications of Experiment 1, the differences may not be out of the ordinary.

Effects of signals. Each rat was exposed to five pairs of conditions in which the same delay to shock was evaluated with and without the signal. Effects of the signaling procedure were mixed, as illustrated by the undifferentiated data paths in most of the right-hand panels of Figure 10. To evaluate whether indifference points in Signal and No-Signal conditions with equivalent delays to shock were reliably different, sign tests were conducted on the 96 adjusting delays that constituted the indifference points. Table 6 reports descriptive statistics (means and SDs) of the adjusting delays (s) across blocks of stable sessions in No-Signal and Signal conditions, and the results of the sign tests. For FD6 and FD8, adjusting delays were significantly longer during Signal conditions (7 of 10 cases) in most comparisons and were rarely

Table 5

Experiment 2. Parameters (M and k) for the best fitting hyperbola based on Mazur's equation for each rat for the set of conditions without (N) and with (Y) a signal for delayed shock. The number of indifference points to which Mazur's function was fit is represented by N. VAC is the variance in the indifference points accounted for by the best fitting hyperbola.

Rat	Signal (N/Y)	N	M	k	VAC
FD5	N	6	9.9	0.05	0
	Y	5	10.8	0.08	0
FD6	N	6	5.9	0.05	27
	Y	5	9.8	0.08	49
FD7	N	6	63.4	0.22	92
	Y	5	30.9	0.13	84
FD8	N	6	13.9	0.07	0
	Y	5	16.8	0.08	76
Group Mean	N	6	19.0	0.08	56
	Y	5	14.7	0.05	96

Note. Mazur's equation is $V = M / (1 + k D)$ where V represents the predicted adjusted delay to food at a given fixed delay to shock, M represents the maximum adjusted delay to food, D represents a given fixed delay to shock, k represents the rate at which the effects of delayed shock are degraded for each second that shock is delayed.

Table 6

Experiment 2. Adjusting delay data (mean and SD) and results of sign tests from the 96 stable blocks of No-Signal and Signal conditions. Plus and minus signs were calculated by subtracting the adjusting delay (s) in Signal conditions from the adjusting delay (s) in No-Signal conditions, and the right-most column shows the corresponding p-values. Missing p-values indicate that the test results were not significant at $p < .05$. Plus signs indicate comparisons with a longer delay in No-Signal conditions and minus signs indicate a longer delay in Signal conditions.

Rat	Delay to Shock (s)	No-Signal		Signal		Sign Test		
		Mean	SD	Mean	SD	+	-	$p <$
FD5	2	4.5	2.7	5.0	2.9	30	42	--
	4	9.9	4.4	6.9	5.8	56	24	.001
	8	5.6	3.0	10.8	6.3	15	71	.001
	16	6.3	4.4	7.8	5.0	38	52	--
	64	3.6	3.4	4.1	3.2	38	50	--
FD6	2	3.5	2.4	9.8	3.5	7	88	.001
	4	5.9	2.6	4.3	2.7	56	21	.001
	8	4.3	2.2	6.6	3.6	16	66	.001
	16	3.9	3.5	7.1	4.9	23	60	.001
	64	0.9	1.6	0.5	1.1	20	14	--
FD7	2	63.4	6.3	28.7	8.1	96	0	.001
	4	34.2	5.3	30.9	6.0	60	31	.01
	8	22.7	4.1	18.2	5.0	64	27	.01
	16	13.8	6.3	4.5	3.7	88	5	.001
	64	8.2	4.4	5.9	4.6	67	15	.001
FD8	2	4.4	2.6	12.6	3.4	2	90	.001
	4	13.9	2.9	16.8	2.8	10	70	.001
	8	13.0	3.6	12.8	5.2	44	42	--
	16	8.4	4.8	12.0	5.0	25	57	.01
	64	1.0	1.6	3.5	3.3	5	63	.001

significantly longer during No-Signal conditions (1 of 10 cases). These results suggest that the signaling procedure may have increased effects of shock. For FD5, the signaling procedure did not affect the indifference points systematically. Adjusting delays were significantly different in only two cases. In one of the cases, adjusting delays in the Signal condition were significantly longer and in the other case, adjusting delays in the No-Signal condition were significantly longer. Finally, for FD7, the adjusting delays in No-Signal conditions were significantly longer in all five cases. This suggests that the signals may have decreased effect of delayed shock for FD7.

Overall, the signaling procedure did not systematically increase or decrease the effects of delayed shock. Across all 20 cases in which indifference points in Signal and No-Signal conditions can be compared, Signal conditions produced significantly longer adjusting delays in eight cases, and No-Signal conditions produced significantly longer adjusting delays in six cases. Instead, the variable that most consistently influenced shocks effects was delay. Across conditions of Experiment 2, indifference points decreased as a function of the delay to shock, which generally replicates the findings from Experiment 1.

Adjusting Delays across Blocks of Trials

Figure 11 shows the adjusting delays to food (s) across blocks of trials for each rat during No-Signal (solid black line) and Signal (unfilled gray line) conditions. Phase labels indicate the delay to shock (s) in each condition and phase lines show changes in conditions. As in Experiment 1, adjusting delays prior to the identification of indifference points were often characterized by prominent peaks in adjusting delays, during which time the delay was driven longer than the ultimate delay (e.g., the 16-s signal condition for all rats). This finding was not affected systematically by the presence or absence of the signaling procedure. In the five sets of

Figure 11. *Experiment 2:* Adjusting delay to food (s) plotted across successive blocks of trials in No-Signal (solid black line) and Signal (unfilled gray line) conditions. Phase labels show the fixed delay to shock (s) in each condition and phase lines indicate changes in conditions.

conditions in which adjusting delays in No-Signal and Signal conditions can be compared (2-64 s), there is a high degree of overlap in the pattern of adjusting delays.

There are two locations in Figure 11 at which the pattern of adjusting delays in Signal and No-Signal conditions appear to diverge meaningfully from one another: The 16-s delay conditions (all rats), and the 2-s delay conditions (FD7 only). It appears that the differences in the patterns of adjusting delays found in the 16-s condition may have occurred as a result of initial exposure to the response-dependent shock. For all rats, the maximum adjusted delay recorded in the experiment was recorded in this initial condition. The differences in the patterns shown in the 2-s delay condition for FD7 appears to have occurred because fluctuations in the adjusting delay occurred more rapidly in the Signal condition than in the No-Signal condition. This allowed the adjusting delays to meet the stability criteria after fewer sessions in the No-Signal condition relative to the signal condition. Although in this case, the Signal condition lasted far longer than the No-Signal condition, in general there was no systematic relation for FD7 or any of the other rats between the condition length and the presence of the signaling procedure.

Response Latencies in Forced-Choice Trials

As in Experiment 1, there was interest in whether response latencies indicated that the consequences associated with responding on the two levers were equivalent in value. Figure 12 and Table 7 report the differences in response latencies during forced-choice trials of stable sessions in each condition. The bars in the panels of Figure 12 show the median latency to respond on the single-valence (unfilled) and dual-valence (shaded) levers during forced-choice trials in stable sessions of each condition, and error bars extend from the 25th to 75th percentiles. The x-axis shows the delay to shock programmed in conditions without (No Signal; left column)

Table 7

Experiment 2. Forced-choice latency data (25th, 50th, 75th percentile) and results of sign tests from the 96 stable blocks of each No-Signal and Signal condition. Plus and minus signs were calculated by subtracting the forced-dual-valence latency from the forced-single-valence latency, and the right-most column shows the corresponding p-values. Missing p-values indicate that the test results were not significant at $p < .05$. Plus signs indicate comparisons with a longer latency to respond during single-valence trials and minus signs indicate a longer latency to respond during dual-valence trials.

Fixed Delay to Shock		No-Signal Conditions										Signal Conditions										
		Single-Valence			Dual-Valence			Sign Test			Single-Valence			Dual-Valence			Sign Test					
		25th	50th	75th	25th	50th	75th	+	-	p <	25th	50th	75th	25th	50th	75th	+	-	p <			
FD5	1	0.9	1.2	1.6	0.7	0.9	2.5	55	41	--												
	2	0.9	1.0	1.4	0.7	1.0	1.6	49	47	--				0.9	1.3	1.7	0.9	1.1	2.7	50	46	--
	4	0.9	1.1	1.4	0.7	0.9	1.2	58	36	.05				0.9	1.5	2.3	0.8	1.1	2.0	52	44	--
	8	0.8	1.0	1.2	0.7	0.9	1.5	44	52	--				0.8	1.0	1.5	0.7	0.8	1.6	54	42	--
	16	1.3	1.8	2.7	0.8	0.9	1.6	68	28	.001				1.0	1.2	1.8	0.7	1.0	1.6	59	36	.05
	64	0.9	1.0	1.5	0.7	0.9	1.4	58	37	.05				0.7	0.9	1.5	0.7	0.8	1.4	60	35	.05
FD6	1	1.0	1.3	1.7	0.8	0.9	1.0	77	18	.001												
	2	1.1	1.3	1.5	0.8	0.9	1.0	86	10	.001				1.1	1.3	2.2	0.8	0.9	3.3	63	33	.01
	4	0.9	1.1	1.5	0.8	0.8	1.2	64	32	.01				0.9	1.1	1.3	0.8	0.9	1.1	63	32	.01
	8	0.9	1.0	1.3	0.8	0.8	0.9	69	25	.001				1.1	1.3	1.9	0.8	0.8	1.1	73	23	.001
	16	0.9	1.1	1.5	0.8	0.8	1.0	67	29	.001				1.2	1.9	2.8	0.8	0.8	1.1	89	7	.001
	64	1.0	1.2	2.2	0.8	0.8	1.0	67	28	.001				1.0	1.6	2.9	0.8	0.8	1.0	72	24	.001
FD7	1	0.8	1.0	1.9	4.2	8.5	18.3	9	87	.001												
	2	0.8	1.4	2.6	4.5	17.8	35.0	5	91	.001				0.7	0.7	0.9	4.1	14.2	22.9	3	93	.001
	4	0.6	0.7	0.8	0.6	0.7	1.0	42	53	--				0.6	0.8	1.0	0.7	0.9	2.5	35	61	.05
	8	0.5	0.7	0.8	0.6	0.8	1.3	36	60	.05				0.5	0.6	0.7	0.5	0.7	1.3	30	64	.001
	16	0.5	0.6	0.7	0.5	0.6	1.1	38	58	--				0.6	0.7	0.9	0.6	0.7	0.8	44	52	--
	64	0.4	0.6	0.7	0.7	0.7	1.1	24	71	.001				0.5	0.6	0.7	0.5	0.6	1.0	37	57	--
FD8	1	0.6	0.8	1.0	0.5	0.6	0.8	62	34	.01												
	2	0.6	0.9	1.2	0.6	0.7	0.8	61	33	.01				0.6	0.7	1.2	0.6	0.7	0.8	48	47	--
	4	0.6	0.7	1.3	0.6	0.7	0.9	57	38	--				0.5	0.7	1.3	0.6	0.7	0.9	54	42	--
	8	0.6	0.7	1.2	0.6	0.7	0.8	47	49	--				0.5	0.8	1.4	0.6	0.7	0.9	52	43	--
	16	0.7	0.9	1.4	0.6	0.7	1.0	64	31	.001				0.9	1.2	1.8	0.7	1.0	2.0	58	38	--
	64	0.6	0.9	1.2	0.5	0.6	0.7	57	38	--				0.6	1.0	1.4	0.5	0.7	0.9	67	29	.001

Figure 12. *Experiment 2:* Latency to respond (s) during forced-choice trials in stable sessions across conditions in which delayed shock was not (left column) and was (right column) signaled. Bars show the median latency during forced-single-valence trials (unfilled) and forced-dual-valence trials (shaded). Error bars extend from the 25th to 75th percentiles.

and with (Signal; right column) signaled delayed shock. As in Experiment 1, sign test were conducted on pairs of forced-choice trials in each block of the stable conditions. Table 7 reports the forced-choice latency data and the results of sign tests for each rat in Signal and No-Signal conditions. To facilitate interpretation, *p*-values are included only for comparisons yielding significant results at the .05, .01, and .001 level.

Differences in the latency to respond on the single-valence and dual-valence levers varied across rats. For FD5 and FD8, comparisons of response latencies were significant in less than half of the cases (9 of 22). For FD6 and FD7, most of the comparisons (18 of 22; 82%) produced significant differences. For FD6, the single-valence response latencies were longer in all 11 conditions. In contrast, for FD7, response latencies on the dual-valence lever were longer in each of the seven significant comparisons. Comparisons in which latencies were significantly different did not appear to be affected systematically by the signaling procedure: They were approximately equally likely to occur in Signal and No Signal conditions. Excluding the 1-s delay condition which never included signaled shock, the ratio of significant comparisons in Signal to No-Signal conditions was 2:2 (FD5), 5:5 (FD6), 3:3 (FD7), and 1:3 (FD8).

To find out whether these latencies were related to the immediate consequences associated with the two levers, the median response latencies on the single-valence were plotted as a function of the indifference point in each condition. Figure 13 shows the median response latency during forced-single-valence (top panels) and dual-valence (bottom panels) trials. A linear function was fit to the results in each panel. The slope of the line and the correlation (Pearson's *r*) are located in the middle-right (single-valence) and bottom-right (dual-valence) panels of the figure. Unlike the results found in Experiment 1, in most cases shown in the top

Figure 13. *Experiment 2:* The latency to respond (s) during forced-single-valence (top panels) and dual-valence (bottom panels) trials plotted as a function of the indifference point (s) identified in each condition. Symbols show the median of the 96 latencies to respond during single-valence (filled) and dual-valence (unfilled) trials aggregated over the stable sessions in each condition. The dashed lines show the best-fitting linear function. The table in the middle-right and bottom right panels of the figure shows the slope of the best-fitting linear function and the correlation (Pearson's r) of the two variables.

panels of Figure 13 (FD5, FD6, and FD8), the median latency to respond on the single-valence lever was not correlated with indifference points. This suggests that for most rats (FD5, FD6, and FD8), single-valence latencies were not controlled by the delay to food produced by pressing the single-valence lever. The only rat that showed a direct relation between the latency to respond and the delay to food on the single-valence lever was FD7 ($r = .88$). This was the rat whose indifference points most closely approximated the results produced by the rats in Experiment 1.

As in Experiment 1, the relation between dual-valence latencies and indifference points was also investigated (bottom panels of Figure 13). In contrast to the results found in Experiment 1, the latency to respond during dual-valence trials was positively correlated with the indifference points in for three rats (FD6, FD7, and FD8). Although there is no reason to believe that dual-valence response latencies should be controlled by the delay to food produced by the single-valence lever, results in Figure 10 show that effects of shock are greatest in conditions with short delays to shock and generally produce higher indifference points. Therefore, the positive correlation between dual-valence response latencies and indifference points found for three of the rats may have resulted from the delay to shock.

To find out, the correlation between dual-valence response latencies and the delay to shock was evaluated. Figure 14 shows the dual-valence response latencies plotted as a function of the delay to shock in each condition. For all rats, the direction of the correlation was uniformly negative across rats and the strength of the correlation was comparable to the correlation between dual-valence latencies and indifference points (range: $-.186$ to $-.736$). These results suggest that the correlation found for some rats between dual-valence response latencies and the delay to food on the single-valence lever found resulted from the delay to shock

Figure 14. *Experiment 2.* The latency to respond (s) during forced-dual-valence trials plotted as a function of the delay to shock (s) in each condition. Symbols show the median of the 96 latencies aggregated over the stable sessions in each condition. The dashed line shows the best-fitting linear function. The table in the bottom-right panel of the figure shows the slope of the best-fitting linear function and the correlation (Pearson's r).

programmed in the condition. These results also suggest that, unlike the results from Experiment 1, the delayed shock affected dual-valence response latencies.

Overall, results from the latency analyses show that response latencies during forced-choice trials of Experiment 2 were not solely under the control of the reinforcing consequences associated with the levers. Instead, response latencies on the dual-valence lever appear to have been affected by the delay to shock. The shorter the delay to shock, the weaker responding on the dual-valence lever, shown by the increased dual-valence response latencies.

General Discussion

The present experiments explored choice in which immediate reinforcement was followed by a delayed shock. In Experiment 1, effects of delayed shock on the value of immediate food were examined across conditions in which the delay to shock was manipulated systematically. Generally, shock devalued food to the greatest extent when the delay was short, and effects of shock were weakened systematically as the delay to shock was raised. In Experiment 2, the effect of signaling the delayed shock was evaluated. The signaling procedure did not influence effects of the delayed shock systematically. Whether or not the delayed shock was signaled, effects of shock were similarly weakened as a function of the delay. Across both experiments, effects of delayed shock decayed in a pattern resembling a hyperbola: The effects of shock on the value of immediate food were generally greatest at the shortest delay to shock and often dropped sharply and decayed at a shallow rate thereafter. Although Mazur's (1987) hyperbolic function was moderately successful at describing the results of the experiments at the group level, its fit to the results of individual subjects was inconsistent.

Variables that Affect the Value of a Dual-Valence Consequence

Previous experiments (Rodriguez et al., 2017; Dumas, 2014) have examined choice between a small food reinforcer without shock and a large food reinforcer followed by delayed shock. Rodriguez et al. (2017) evaluated preferences between the two options as the delay to shock following the large reinforcer was changed across blocks in each session. They found that the rats generally preferred the small reinforcer in blocks in which the shock immediately followed the large reinforcer. Choice of the small reinforcer generally declined as the delay between the large reinforcer and shock was raised. Dumas (2014) examined how the value of the large reinforcer was decreased by delayed shock of different intensities (0.2-0.8 mA) and durations (100 or 200 ms). He found that the effectiveness of delayed shock at devaluing the large reinforcer changed as a function of its intensity and duration.

The results from the present experiments add to the limited research on choice that produces both reinforcing and aversive consequences. Similar to Dumas's (2014) experiment, the present experiments explored how delayed shock devalues an immediate reinforcer. Similar to Rodriguez et al.'s (2017) experiment, the present experiments examined how delay changes effects of shock. Unlike the previous experiments however, the same amount of food was produced in both consequences. In the present experiments, shock devalued the immediate food as an inverse function of the delay to shock. When the delay to shock was short, it was most effective at reducing the value of immediate food. As the delay to shock was raised, its effects were weakened systematically. These results extend Rodriguez et al.'s (2017) finding that effects of shock are weakened by delay using a procedure that identified the value of the consequences, instead of preferences for the consequences. Together with Dumas (2014), these

findings show that the value of a dual-valence consequence is affected by the intensity, duration, and delay of the aversive consequence.

Effects of Signaling Delayed Shock

Experiment 2 used a signaling procedure meant to address potential limitations of the procedure used in an unpublished follow-up to Dumas's (2014) experiment. In the unpublished follow-up study, sessions took place as described in Dumas's (2014) experiment. Rats chose between a small food reinforcer (one food pellet) and a large food reinforcer (two or three food pellets) followed by shock delivered after an adjusting delay. Across conditions, shock intensity and duration were manipulated, and in some conditions, a signal was delivered in which the houselight pulsed continuously between the delivery of the large reinforcer and the delayed shock. The signal did not influence effects of the delayed shock systematically. It was reasoned that ineffectiveness of the signal could have been caused by properties of the stimulus used to signal shock (pulsing houselight) or the variability in the length of the signal resulting from adjustments in the delay to shock.

To address these possibilities, the signaling procedure used in Experiment 2 of the present study included signals with both visual and auditory stimulation: Turning the houselight and the white noise off and on. It also used a signaling procedure which removed variability in the length of the signal across the varying delays to shock by delivering the signal for 2 s following the delivery of food and for 2 s immediately preceding shock. Despite addressing these potential issues, this signaling procedure was ineffective. Because previous research has found evidence that signaling delayed aversive consequences can attenuate effects of delay and increase effects of an aversive consequence (e.g., Bevin & Dukes, 1955; Byrne & Poling, 2017;

Tedford, 1969; Trenholme & Baron, 1975; Vogel-Sprott, 1966), it is difficult to interpret the absence of systematic effects of the present signaling procedure.

One explanation for the lack of a systematic effect of the signals is that the signals used in Experiment 2 and in the unpublished follow-up to Dumas's (2014) experiment were redundant. In both experiments, a signal was provided following the presentation of food resulting from a press on the dual-valence lever. Therefore, in both experiments, two stimuli consistently predicted shock, independent of the presentation of signals: (a) pressing the dual-valence lever and (b) the immediate presentation of two (or three) food pellets.

It seems unlikely that redundancy can explain the present results because the same criticism could be made of effective signaling procedures used in previous experiments. For example, in half of the trials in Trenholme and Baron's (1975) first experiment, a student's first response produced a flash of green light, indicating that five cents were earned. In the other half of trials, the response did not produce a green light, and instead produced a red light after a delay indicating that five cents were lost. Even without using a signal, the absence of the green light following a response indicated that the student would be losing money. Still, money-losses delayed by 20 s or 40 s did not punish responding in Experiment 1. In Experiment 2, signals were provided following responding that produced money-losses. The signals increased the punishing effects of money-losses such that losses delayed by 20 s or 40 s effectively punished responding, even though the absence of the green light was still predictive of money losses. A similar amount of redundancy can be found in Byrne and Poling's (2017) experiment. In their experiment, rats could press either of two levers, each of which produced 4-s access to sweetened condensed milk. In some conditions, responding on one of the levers also produced a 10-s period in which no milk could be earned (timeout) after a delay (4-38 s). Although one

lever was consistently associated with delayed timeout, signals still increased the punishing effects of the delayed timeout. These experiments show that signals can still increase effects of delayed aversive consequences even when the signals are redundant.

A second explanation for the lack of a systematic effect of the signal is that the two presentations of the signal (2-s after food and 2-s before shock) may have had opposite influences on the effects of the delayed shock. Opposing effects of signals have been shown by two lines of research. In the first line of research, the signal and the aversive event are both delivered contingent upon responding and the signal immediately follows the responding (e.g., Bevin & Dukes, 1955; Byrne & Poling, 2017; Tedford, 1969; Trenholme & Baron, 1975; Vogel-Sprott, 1966). This research has produced evidence that signaling procedures *increase* effects of delayed aversive consequences. For example, in Trenholme and Baron's (1975) second experiment, response-dependent signals were delivered immediately following the response that produced money-losses, and the signals increased the punishing effects of the response-dependent money-losses.

A second line of research on signaling delayed shock provided signals in situations in which shocks were delivered independent of responding. This line of research has found that signals *decrease*, rather than increase, effects of delayed shock (Badia, Coker, & Harsh, 1973; Badia, Culbertson, & Harsh, 1973; Fanselow, 1979; Lockard, 1963; see Badia, Harsh, & Abbott, 1979 for a review). For example, Badia, Culbertson, and Harsh (1973; Experiment 2) examined rats' preferences between unsignaled shock and signaled shock across conditions in which the signaled shock was made unfavorable through increases in the intensity of shock. In sessions, unsignaled shocks were delivered after varying periods of time unless the rat pressed a lever that changed, for 3 min, to a situation in which the shocks were preceded by a 5-s tone. Rats could

remain in the signal situation by pressing the lever before the end of a 3-min period. In conditions in which the shocks delivered in signaled and unsignaled periods were the same intensity (1.0 mA, 500-ms duration), rats pressed the lever regularly and remained in the signaled situation for more than 90 percent of the session on average – indicating a strong preference for signaled shock. Across conditions, preference for the signaled shock remained even though the intensity of the shock in the signaled situation was raised. When the intensity of the signaled shock was raised to 2.2 mA, the rats spent an average of 65 percent of session in the signal situation – indicating that the signal reduced the aversive effects of 2.2-mA shock to the extent that these shocks were less aversive than unsignaled shock of a much lower intensity.

In Experiment 2, the signal was delivered in two temporal locations: For 2 s immediately following the food, and for 2 s immediately preceding the delayed shock. Considering the two lines of research described above, it is possible that the mixed effects of the signals could be a product of the opposing effects produced by signaling the delayed shock at these two locations. As in the first line of research, the signal and the aversive event were both delivered contingent upon responding (pressing the dual-valence lever), and the signal followed food immediately. This may have increased effects of the delayed shock. As in the second line of research, the second part of the signal immediately preceded the delayed shock. This may have decreased effects of delayed shock by allowing rats to prepare for the delivery of the aversive stimulus (e.g., specific muscle tension or body position), which has been suggested as the mechanism by which signals reduce the effects of delayed shock (Perkins, 1955; Mowrer 1960; see Badia, Harsh, & Abbott, 1979 for a review). Whereas muscle tension and body-position may have allowed rats to contact less aversive shock, these kinds of responses may not reduce the aversiveness of other consequences such as money-losses (Trenholme & Baron, 1975) or periods

in which reinforcers are not available (Byrne & Poling, 2017). This might explain the clear results obtained in some previous experiments. Therefore, it is possible that signaling procedures like the one used in this experiment may still increase effects of delayed aversive consequences provided that the consequences are not susceptible to decreases through preparatory responding.

To determine whether opposing effects of signaling delayed shock, acting in concert, might account for the mixed effects of the signal in the present experiment, future research might examine effects of presenting a signal with elements common to only one of the lines of research. For example, if a signal is no longer presented immediately after food and presented only immediately before shock, it might be possible to retain the signal's ability to decrease effects of shock while removing the signal's ability to increase effects of shock. It should be noted that this strategy might allow researchers to understand effects of signaling delayed shock, but would not be useful if the goal of the research is to increase effects of delayed shock.

Block-by-Block Analysis of Adjusting Delays

In his analysis of the adjusting delay across blocks of trials, Dumas (2014) noted a pattern in the adjusting delays prior to the identification of indifference points which differed from those described in previous studies. The same pattern of adjusting delays was found occasionally in the present set of experiments. This pattern is illustrated in Figure 15, which shows the adjusting delay to shock for AD5 (Dumas, 2014) and the adjusting delay to food for FD1 (Experiment 1) across blocks of a condition with the same shock parameters (0.8 mA, 200-ms duration). The letters in the panel mark points of reference, the bracket shows the stable adjusting delays, and the dashed line shows the indifference point identified in the condition. Beginning at point "A," near-exclusive responding occurred on the single-valence lever, which raised the adjusting delay

Figure 15. Adjusting delays (s) across successive blocks of trials for FD1 (Experiment 1; 2-s delay to shock, initial exposure) and AD5 (Dumas, 2014). For both rats shown above, the shock that makes up half of the dual-valence consequence was 0.8 mA and lasted 200 ms. The adjusting delays from point “A” to point “C” indicate periods of predominant choice of the single-valence consequence (1 or 2 pellets, no shock). Adjusting delays from point “D” to point “F” indicate periods of predominant choice of two pellets plus delayed shock. The bracket marks the stability period. See text for further discussion of points “B” and “E.”

to its highest point “C,” a point well longer than the ultimate indifference point. Then, at point “D” responding occurred nearly exclusively on the dual-valence lever until point “F,” when responding on the two levers began to alternate more frequently. Points “B” and “E” show points in which the adjusting delay was equivalent, but the pattern of responding was opposite. At point “B,” responding occurred nearly exclusively on the single-valence lever, whereas at point “E” responding occurred on the dual-valence lever. This pattern shows that the rat was exposed to the terminal delay multiple times prior to the identification of an indifference point, and that choice may depend in part on the responses made recently.

It is possible that these short-lived peaks in adjusted delays result from an association between an effective punishing consequence (0.8-mA shock, 200-ms duration) delivered in close temporal proximity to a response. In the method used in the present experiments and by Dumas (2014), the dual-valence lever was consistently associated with shock. At point “A” in the left panel of Figure 15, AD5 first produces the shock at its shortest-possible delay, 4 s following the delivery of food. Similarly, point “A” in the right panel occurs at the initial exposure to shock delivered 2-s after food. Because of the association between the lever and this effective punisher, it follows that responding might be allocated to the other lever for a time. It is unclear exactly what variables are responsible for the height of the peak, but the present experiments provide a clue. Peaks are usually the highest in the first condition and in the condition with the shortest delay to shock. It also appears that some of the rats were more likely to show peaks than other rats, which indicates differences in sensitivity to the delayed shock. Should future researchers be interested in evaluating methods to maximize momentary reactions to delayed aversive consequences, they may consider investigating procedures that can increase the height or prolong the duration of these short-lived peaks.

Response Latencies

In every condition, the delay to food was adjusted until the two consequences – immediate food followed by delayed shock and delayed food alone – were functionally equivalent based on a rat's choices. Although choice between the consequences indicated that they were equivalent in value, the latency to respond on the two levers indicated that the consequences were not equivalent during some of these periods. In Experiment 1, sign tests showed that latencies to press the lever that produced delayed food alone were significantly longer than latencies to press the lever that produced immediate food with delayed shock in 48 percent of comparisons. In contrast, latencies to respond on the lever that produced immediate food with delayed shock were rarely significantly longer – only 7 percent of comparisons. These results suggest that, whereas choice between the consequences was under equal control of the immediate food followed by delayed shock and the delayed food alone, the response latencies were under the control of the delay to food. When response latencies were plotted as a function of the delay to food, latencies to press the lever that produced delayed food were positively correlated with the delay to food. When the same analysis was conducted with dual-valence latencies, the correlation was absent. These results are consistent with the interpretation that the latency to respond on the two levers were controlled by the delay to the reinforcing consequences associated with each lever. The latency to respond on the lever that produced delayed food alone tended to (a) be longer than the latency to press the lever that produced food immediately, and (b) increase as a function of the delay to food.

An interpretation of these results is that two aspects of behavior may be differentially controlled by aspects of the dual-valence consequence: choice was controlled by a combination of the immediate food and delayed shock, whereas response latency was controlled by the

immediacy of the food. At the point in a condition at which an indifference point was identified, choice produced both consequences equally often. At the same time, response latencies were under the control of the reinforcing consequences produced by pressing each lever. The immediate production of food following a press on the dual-valence lever maintained short response latencies, despite the fact that this option also produced delayed shock, and the delayed production of food following a press on the single-valence lever maintained long response latencies. These results provide evidence that different features of responding can be under simultaneous control by aspects of dual-valence consequences.

Experiment 2 produced results that suggest that although the signaling procedure did not have a systematic effect on choice, signaling the delayed shock may have affected response latencies. Unlike the results from Experiment 1, the analysis of response latencies in Experiment 2 revealed a negative correlation for all rats between the latency to press the lever that produced immediate food followed by delayed shock and the delay to shock. These results suggest that the latency to respond on the dual-valence lever was controlled to some extent by the delayed shock. Because the major difference between the procedures used in Experiment 1 and Experiment 2 is that signals were presented in half of the conditions of Experiment 2, these results are partially consistent with the interpretation that the signaling procedure was responsible for establishing control of dual-valence response latencies by the delayed shock. The problem is that Signal conditions did not consistently produce longer dual-valence response latencies than No-Signal conditions. Because dual-valence response latencies were not higher in Signal conditions, this means that if the signal increased control of response latencies by the delayed shock in Experiment 2, then this effect was not limited to Signal conditions, but occurred at a global level following exposure to the signaling procedure.

Mazur's Hyperbolic Discounting Equation

Mazur's (1987) hyperbolic discounting function allows researchers to characterize the value of delayed consequences based on the maximum effects of consequences and the rate at which those effects decay as they are delayed:

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

Where V represents the value of the consequence at a given delay, M represents the maximum (or undiscounted) effects of the delayed consequence, and D represents the delay to the consequence. The k describes the rate at which the value of the consequence is degraded per unit of delay.

Mazur's (1987) function provides researchers with an analytical tool that allows them to characterize and compare patterns of choices across individuals or species with histories or predispositions associated with making impulsive choices and examine effects of environmental manipulations. For example, Madden et al. (1997) found that opioid-dependent individuals discount hypothetical money at a higher rate than individuals without an opioid dependency, suggesting that patterns of impulsive choice may be predicted by an individual's history. Similarly, Huskinson, Krebs, and Anderson (2009) showed that Lewis rats discount the value of a large food reinforcer at a higher rate than Fischer 344 rats, and that acute administration of *d*-amphetamine can decrease effects of delay for Lewis rats, but not Fischer 344 rats. This finding shows that patterns of impulsive choice may be predicted based on subject characteristics such as the strain of a rat, and that environmental manipulations such as drug administration may have systematic and strain-specific effects on choice. Comparisons of the k parameter produced by fitting Mazur's (1987) function allow correlations of this nature to be identified.

Mazur's (1987) function was fit to the individual and group results from both experiments. When the group and individual indifference points were plotted as a function of the delay to shock in the present experiments, the pattern often resembled a hyperbola; however, the fit of the function varied depending on whether it was fit to individual or group results. The group results were described moderately well by Mazur's (1987) function. In the two cases (initial and replicated conditions) in which the function was fit to the group results from all rats in Experiment 1, the function fit the results well (VAC: 91-96%). When the function was fit to the group results from Experiment 2, it fit the results with varying success depending on whether signals were provided (VAC: 96%) or not (VAC: 56%). The fit of the function to the group results in the present experiment are somewhat similar to those produced by Rodriguez et al.'s (2017) study, who also examined choice involving dual-valence consequences and found Mazur's function to describe the group results well (VAC: 81-87%).

Whereas Mazur's (1987) function fit the group results with moderate success, it was often a poor fit to the results from individual rats. Across the two experiments, the equation described the results of individual rats well ($VAC > 80\%$) in only 7 of 16 cases. The poor fit of the function to the individual results stands in contrast to the results normally produced using delay-of-gratification paradigm. It is possible that the poor fit occurred because the present experiments involved consequences of both positive and negative valence. This possibility seems unlikely, however, given the fit of the function to the group results and the results from Rodriguez et al.'s (2017) experiment. When the function was fit to the proportion choice results of individual rats in Rodriguez et al.'s study, it accounted for a moderate-to-high percent of the variance (VAC: 64-98%).

The inconsistent fit of Mazur's (1987) function to the results of the present experiments cast doubt upon whether comparisons of k -values – the rate at which effects of shock were weakened – should be made between the present experiments and those obtained in other choice situations. In the present experiments, Mazur's (1987) function normally fit the results from individual rats poorly. Although the group results generally (a) show clear relations between indifference points and the delay to shock and are described well by Mazur's (1987) function, it is unclear whether they are a good characterization of the findings of the present experiments because the group results do not accurately describe results from any of the individual rats. Therefore, the function produced by fitting Mazur's (1987) equation to the group results cannot be used to predict choice at a given delay for any of the rats. Because of this, the clear functions shown by the group results may, in actuality, provide little information about how delay affects shock in choice between delayed food alone and immediate food followed by delayed shock.

Conclusion

The present experiments explored variables that affect choice involving both reinforcing and aversive consequences. Experiment 1 found that immediate food is devalued by delayed shock, and that the effects of delayed shock decrease as a negative function of the delay to shock. This finding replicates the general finding of Rodriguez et al. (2017), which showed that effects of delayed shock on preference are weakened as a function of delay. Together with Dumas (2014), the findings on choice that produces both reinforcing and aversive consequences indicate that the value of the reinforcing consequence is degraded by the aversive consequence as a direct function of the intensity and duration of the consequence and as an inverse function of the delay to the aversive consequence.

The signaling procedure evaluated in Experiment 2 did not have a systematic effect on delayed shock. These results are inconsistent with the findings produced by experiments on

signaling delayed punishment, and may result from opposing effects produced by the present signaling procedure. Future research might consider exploring the role of signals in choice involving both reinforcing and aversive consequences.

Future research is needed to determine whether the present results have downstream implication for translation to clinical research and practice. Although the findings from the present experiments are not directly useful for clinical settings, it follows that the discovery of variables that affect choice that produces both reinforcing and aversive consequences may eventually benefit individuals who habitually produce consequences of conflicting valence.

References

- Ainslie, G. (1974). Impulse control in pigeons. *Journal of the Experimental Analysis of Behavior*, 21, 485–489.
- Azzi, R., Fix, D. S. R., Keller, F. S., & Rocha e Silva, M. I. (1964). Exteroceptive control of response under delayed reinforcement. *Journal of the Experimental analysis of Behavior*, 7, 159-162.
- Badia, P., Culbertson, S., & Harsh, J. (1973). Choice of longer or stronger signalled shock over shorter or weaker unsignalled shock. *Journal of the Experimental Analysis of Behavior*, 19, 25-32.
- Baron, A. (1965). Delayed punishment of a runway response. *Journal of Comparative and Physiological Psychology*, 60, 131-134.
- Bevan, W. & Dukes, W. F. (1955). Effectiveness of delayed punishment on learning performance when preceded by premonitory cues. *Psychological Reports*, 1, 441-448.
- Bickel, W. K., Odum, A. L., & Madden, G. J. (1999). Impulsivity and cigarette smoking: Delay discounting in current, never, and ex-smokers. *Psychopharmacology*, 146, 447-454.
- Bouton, M. E. & Bolles, R. C. (1979). Role of conditioned contextual stimuli in reinstatement of extinguished fear. *Journal of Experimental Psychology*, 5, 368-378.
- Byrne, T. & Poling, A. (2017). Behavioral effects of delayed timeouts from reinforcement. *Journal of the Experimental Analysis of Behavior*, 107, 208-217.
- Camp, D. S., Raymond, G. A., & Church, R. M. (1967). Temporal relationship between response and punishment. *Journal of Experimental Psychology*, 74, 114-123.
- Calvert, A. L., Green, L., & Meyerson, J. (2010). Delay discounting of qualitatively different reinforcers in rats. *Journal of the Experimental Analysis of Behavior*, 93, 171-184.

- Cardinal, R. N., Daw, N., Robbins, T. W., & Everitt, B. J. (2002). Local analysis of behavior in the adjusting-delay task for assessing choice of delayed reinforcement. *Neural Networks*, *15*, 617-634.
- Coffey, S. F., Gudleski, G. D., Saladin, M. E., & Brady, K. T. (2003). Impulsivity and rapid discounting of delayed hypothetical rewards in cocaine-dependent individuals. *Experimental and Clinical Psychopharmacology*, *11*, 18-25.
- Dumas, A. D. (2014). *Choice between reinforcers with and without delayed shock*. Unpublished master's thesis, West Virginia University, Morgantown, West Virginia.
- Epstein, R. (1984). An effect of immediate reinforcement and delayed punishment, with possible implications for self-control. *Journal of Behavior Therapy and Experimental Psychiatry*, *15*, 291-298.
- Estle, S. J., Green, L., Myerson, J., & Holt, D. D. (2007). Discounting of monetary and directly consumable rewards. *Psychological Science*, *18*, 58-63.
- Freeman, K. B., Green, L., Myerson, J., & Woolverton, W. L. (2009). Delay discounting of saccharin in rhesus monkeys. *Behavioral Processes*, *82*, 214-218.
- Green, L., Myerson, J., Shah, A. K., Estle, S. J., & Holt, D. D. (2007). Do adjusting-amount and adjusting-delay procedures produce equivalent estimates of subjective value in pigeons? *Journal of the Experimental Analysis of Behavior*, *87*, 337-347.
- Huskinson, S. L., Krebs, C. A., & Anderson, K. G. (2012). Strain differences in delay discounting between lewis and fischer 344 rats at baseline and following acute and chronic administration of *d*-amphetamine. *Pharmacology Biochemistry and Behavior*, *101*, 403-416.

- Johnson, M. W. & Bickel, W. K. (2002). Within-subject comparison of real and hypothetical money rewards in delay discounting. *Journal of the Experimental Analysis of Behavior*, 77, 129-146.
- Johnson, M. W. & Bruner, N. R. (2012). The sexual discounting task: HIV risk behavior and the discounting of delayed sexual rewards in cocaine dependence. *Drug and Alcohol Dependence*, 123, 15-21.
- Kamin, L. J. (1959). The delay-of-punishment gradient. *Journal of Comparative and Physiological Psychology*, 52, 44-51.
- Kirby, K. N., Petry, N. M., & Bickel, W. K. (1999). Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls. *Journal of Experimental Psychology: General*, 128, 78-87.
- Lattal, K. A. (1984). Signal functions in delayed reinforcement. *Journal of the Experimental Analysis of Behavior*, 42, 239-253.
- Lattal, K. A. (1987). Considerations in the experimental analysis of reinforcement delay. In M. L. Commons, J. E. Mazur, J. A. Nevin, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol 5. The effect of delay and intervening events on reinforcement value* (pp. 107-123). Hillsdale, NJ: Erlbaum.
- Li, C., Balluz, L. S., Okoro, C. A., Strine, T. W., Lin, J. M. S., Town, M., Garvin, W., Murphy, W., Bartoli, W., & Valluru, B. (2011). Surveillance of certain health behaviors and conditions among states and selected local areas—Behavioral Risk Factor Surveillance System, United States, 2009. *Morbidity and Mortality Weekly Report: Surveillance Summaries*, 60, 1-249.

- Madden, G. J., Bickel, W. K., & Jacobs, E. A. (1999). Discounting of delayed rewards in opioid-dependent outpatients: Exponential or hyperbolic discounting functions? *Experimental and Clinical Psychopharmacology*, 3, 284-293.
- Madden, G. J., Petry, N. M., Badger, G. J., & Bickel, W. K. (1997). Impulsive and self-control choices in opioid-dependent patients and non-drug-using control participants: Drug and monetary rewards. *Experimental and Clinical Psychopharmacology*, 5, 256-262.
- Mazur, J. E. (1987). An adjusting procedure for studying delayed reinforcement. In M. L. Commons, J. E. Mazur, J. A. Nevin, & H. Rachlin (Eds.), *Quantitative analyses of behavior: Vol 5. The effect of delay and intervening events on reinforcement value* (pp. 55-73). Hillsdale, NJ: Erlbaum.
- Miedl, S. F., Peters, J., & Büchel, C. (2012). Altered neural reward representations in pathological gamblers revealed by delay and probability discounting. *Archives of General Psychiatry*, 69, 177-186.
- Mischel, W. & Ebbesen, E. E. (1970). Attention in delay of gratification. *Journal of Personality and Social Psychology*, 16, 329-337.
- Mischel, W., Shoda, Y., & Peake, E. K. (1988). The nature of adolescent competencies predicted by preschool delay of gratification. *Journal of Personality and Social Psychology*, 54, 687-696.
- Mischel, W., Shoda, Y., & Rodriguez, M. L. (1989). Delay of gratification in children. *Science*, 244, 933-938.
- Mowrer, O. H. & Ullman, A. D. (1945). Time as a determinant in integrative learning. *Psychological Review*, 52, 61-90.

- Myerson, J., & Green, L. (1995). Discounting of delayed rewards: Models of individual choice. *Journal of the Experimental Analysis of Behavior*, 64, 263-276.
- Odum, A. L. (2011). Delay discounting: I'm a k, you're a k. *Journal of the Experimental Analysis of Behavior*, 96, 427-439.
- Perone, M. & Galizio, M. (1987). Variable-interval schedules of timeout from avoidance. *Journal of the Experimental Analysis of Behavior*, 47, 97-113.
- Peterson, J. R., Hill, C. C., & Kirkpatrick, K. (2015). Measurement of impulsive choice in rats: Same and alternate form test-retest reliability and temporal tracking. *Journal of the Experimental Analysis of Behavior*, 103, 166-179.
- Pope, D. A., Newland, C., & Hutsell, B. A. (2015). Delay-specific stimuli and genotype interact to determine temporal discounting in rapid-acquisition procedure. *Journal of the Experimental Analysis of Behavior*, 103, 450-471.
- Prusky, G. T., Harker, K. T., Douglas, R. M., & Whishaw, I. Q. (2002). Variation in visual acuity within pigmented, and between pigmented and albino rat strains. *Behavioral Brain Research*, 136, 339-348.
- Rachlin, H., Raineri, A., & Cross, D. (1991). Subjective probability and delay. *Journal of the Experimental Analysis of Behavior*, 55, 233-244.
- Richards, R. W. (1981). A comparison of signaled and unsignaled delay of reinforcement. *Journal of the Experimental Analysis of Behavior*, 35, 145-152.
- Rodriguez, W., Bouzas, A., & Orduña, V. (2017). Temporal discounting of aversive consequences in rats. *Learning & Behavior*. Retrieved from <https://doi.org/10.3758/s13420-017-0279-9>

- Shoda, Y., Mischel, W., & Peake, P. K. (1990). Predicting adolescent cognitive and self-regulatory competencies from preschool delay of gratification: Identifying diagnostic conditions. *Developmental Psychology*, 26, 978-986.
- Skinner, B. F. (1953). *Science and human behavior* (pp. 230-241). New York: Macmillan.
- Tedford, W. H. (1969). Effect of delayed punishment upon choice behavior in the white rat. *Journal of Comparative and Physiological Psychology*, 69, 673-676.
- Trenholme, I. A. & Baron, A. (1975). Immediate and delayed punishment of human behavior by loss of reinforcement. *Learning and Motivation*, 6, 62-79.
- Vuchinich, R. E. & Simpson, C. A. (1998). Hyperbolic temporal discounting in social drinkers and problem drinkers. *Experimental and Clinical Psychopharmacology*, 6, 292-305.
- Vogel-Sprott, M. D. (1966). A classical conditioning procedure to control suppression of a rewarded response punished after delay. *Psychological Reports*, 19, 91-98.
- Weller, R. E., Cook, E. W., Avsar, K. B., & Cox, J. E (2008). Obese women show greater delay discounting than healthy-weight women. *Appetite*, 51, 563-569.
- Woolverton, W. L., Freeman, K. B., Myerson, J., & Green, L. (2012). Suppression of cocaine self-administration in monkeys: Effects of delayed punishment. *Psychopharmacology*, 220, 509-517.
- Woolverton, W. L., Meyerson, J. & Green, L. (2007). Delay discounting of cocaine by rhesus monkeys. *Experimental Clinical Psychopharmacology*, 15, 238-244.

Appendix A

Sample Growth Charts

1. Ad libitum weights were measured and recorded when the rats were 11 weeks old and the weight for each rat was placed in the row labeled “Initial Ad Lib Weights (Day 77).”
2. The row labeled “Calendar Date” begins when each rat was 11 weeks old and a new target weight for each rat was calculated every week for weeks 11-14, every 2 weeks for weeks 16-20, and every 4 weeks for weeks 24-60.
3. Target weights were calculated via the following steps:
 - a. Relative gain (the amount of weight each rat should gain) was determined by subtracting the 11-week ad lib weight for each rat by the projected weight (based on growth charts provided by the supplier for male Sprague-Dawley rats) and dividing this result by the 11-week weight.
 - b. One was added to the relative gain and 80 percent of this value was calculated.
 - c. This product was multiplied by the initial 11-week weight.

Target Weights for FD Rats										
		<i>Initial Ad Lib Weights (Day 77) --></i>	324	330	326	316	338	334	318	332
Weeks	Days	Calendar Date	FD1	FD9	FD3	FD4	FD5	FD6	FD7	FD8
11	77	Friday, December 15, 2017	259	264	261	253	270	267	254	266
12	84	Friday, December 22, 2017	273	278	275	266	285	281	268	280
13	91	Friday, December 29, 2017	283	288	285	276	295	292	278	290
14	98	Friday, January 5, 2018	293	299	295	286	306	302	288	301
16	112	Friday, January 19, 2018	304	309	305	296	317	313	298	311
18	126	Friday, February 2, 2018	317	323	319	309	331	327	311	325
20	140	Friday, February 16, 2018	331	337	333	323	345	341	325	339
24	168	Friday, March 16, 2018	344	351	347	336	359	355	338	353
28	196	Friday, April 13, 2018	358	365	360	349	374	369	351	367
32	224	Friday, May 11, 2018	368	375	371	359	384	380	362	377
36	252	Friday, June 8, 2018	379	386	381	369	395	390	372	388
40	280	Friday, July 6, 2018	389	396	391	379	406	401	382	398
44	308	Friday, August 3, 2018	392	399	395	383	409	404	385	402
48	336	Friday, August 31, 2018	399	406	401	389	416	411	392	409
52	364	Friday, September 28, 2018	409	417	412	399	427	422	402	419
56	392	Friday, October 26, 2018	409	417	412	399	427	422	402	419
60	420	Friday, November 23, 2018	413	420	415	402	431	425	405	423

**West Virginia University Electronic
Thesis and Dissertation Signature
Form**

Student Name: Toegel Forrest James
(Last) (First) (Middle)

Student ID #: 800124204 Non-WVU Email Account: toegel fj@gmail.com

Degree: _____ Master's ☒ Doctorate

Document Type: _____ Thesis ☒ Dissertation

Document Title: Effects of Delay and Signals on Choice between Delayed Food
Alone and Immediate Food with Delayed Shock

Student Agreement:

I hereby certify that, if appropriate, I have obtained and attached hereto a written permission statement from the owners of each third party copyrighted matter to be included in my thesis, dissertation, project report, or other research material, allowing distribution as specified upon deposit.

I hereby grant to West Virginia University and its agents the non-exclusive license to archive and make accessible, under the conditions selected upon deposit, my above mentioned document in whole or in part in all forms of media, now or hereafter known. I retain ownership rights as specified in the WVU copyright policy to the copyright of the abovementioned document. I also retain the right to use in future works (such as articles or books) all or part of this abovementioned document.

Review and Acceptance:

The above mentioned document has been reviewed and accepted by the student's advisory committee. The undersigned agree to abide by the statements above, and agree that this Signature Form updates any and all previous Signature Forms submitted heretofore.

Signed:	<u>Forrest Toegel</u>	<u>11/26/18</u>
	(Student)	(date)
Committee:	<u>Michael Peltre</u>	<u>11-30-18</u>
	(Committee Chair)	(date)
	<u>Ben Edwards</u>	<u>11/26/18</u>
	(Committee Member)	(date)
	<u>Alvin Beull</u>	<u>11/26/18</u>
	(Committee Member)	(date)
	<u>Andy Zolt</u>	<u>11-26-18</u>
	(Committee Member)	(date)
	<u>Sarah Anderson</u>	<u>11-26-18</u>
	(Committee Member)	(date)
	_____	_____
	(Committee Member)	(date)