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Effects of Reinforcer Magnitude and *d*-Amphetamine on Delay Discounting in Rats

William J. P. Reilly

Thesis submitted to the Eberly College of Arts and Sciences at
West Virginia University
in Partial Fulfillment of the Requirements for the Degree of

Master of Science
in
Psychology

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2012

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ABSTRACT

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William J. P. Reilly

Delay-discounting procedures are commonly employed to study impulsive choice, which can be defined as choice for a smaller, more immediate reinforcer over a larger, more delayed reinforcer. Differences in reinforcer magnitude have been shown to alter delay discounting with human participants, but results have been mixed with non-human animals. It is also unclear what impact the absolute difference between a smaller, more immediate and a larger, more delayed reinforcer has on choice in a delay-discounting context. Therefore, in Experiment 1 of the present study, effects of different reinforcer magnitudes on delay discounting in rats were examined using a discrete-trials procedure where the absolute, but not relative, difference in smaller, immediate and larger, delayed reinforcers was altered. It was found that rates of delay discounting were lower when choice was between one immediate and three delayed reinforcers (Small-Magnitude Condition), compared to when choice was between two immediate and six delayed reinforcers (Large-Magnitude Condition). *d*-Amphetamine has been found to alter delay discounting, and baseline levels of delay discounting have been found to be correlated with effects of *d*-amphetamine on choice. As reinforcer magnitude altered baseline rates of delay discounting in Experiment 1, in Experiment 2, effects of various doses of *d*-amphetamine (0.1, 0.3, 1.0, and 1.8 mg/kg) on delay discounting were examined in the context arranged in Experiment 1. In general, *d*-amphetamine decreased delay discounting when rates were relatively high (Small-Magnitude Condition) and increased delay discounting when rates were relatively low (Large-Magnitude Condition), suggesting that baseline rates of delay discounting can influence effects of *d*-amphetamine on delay discounting.

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Introduction

Impulsivity is thought to underlie many behavioral problems, such as attention deficit/hyperactivity disorder (ADHD), pathological gambling, and drug abuse (American Psychiatric Association, 2000). Impulsivity can be operationally defined as choosing a smaller, more immediate reinforcer over a larger, more delayed reinforcer, whereas self-controlled choice can be operationally defined as choosing a larger, more delayed reinforcer over a smaller, more immediate reinforcer (Anslie, 1975; Rachlin & Green, 1972). Therefore, both reinforcer delay and reinforcer amount are important variables controlling choice. Better understanding of factors that influence impulsive choice is important for the prevention and treatment of disorders characterized by impulsivity.

Delay Discounting

Mazur (1987) showed that when choice is between a smaller, immediate reinforcer and a larger, immediate reinforcer, choice for larger reinforcer is observed. However, as delay to the larger reinforcer increases, choice for the larger reinforcer decreases (i.e., the value of the large reinforcer is discounted) in a hyperbolic fashion, a finding that has been replicated in many animal species, such as rats (Mazur & Biondi, 2009; Richards, Mitchell, de Wit, & Seiden, 1997), pigeons (Green, Myerson, Holt, Slevin, & Estle, 2004; Green, Myerson, Shah, Estle, & Holt, 2007; Mazur & Biondi), and humans (Green, Myerson, & McFadden, 1997; Johnson & Bickel, 2002; Kirby, 1997). Thus, delay discounting provides a framework for studying variables that determine impulsive choice.

Evenden and Ryan's (1996) discrete-trials procedure has been commonly used when evaluating delay discounting (e.g., Anderson & Woolverton, 2005; Diller, Saunders, & Anderson, 2008; Cardinal, 2000; Stanis, Avila, White, & Gulley, 2008; Slezak & Anderson,

2008; Winstanley, Theobald, & Dalley, 2005). In this procedure, choice is between a smaller, immediate and larger, delayed reinforcer. The delay associated with the larger reinforcer is gradually increased within the session, allowing for generation of delay-discounting functions within a single session. From these functions, area under the curve (AUC) can be calculated and used as measures of delay discounting, with higher AUC values corresponding to lower rates of delay discounting or decreased impulsive choice.

Delay Discounting and Reinforcer Magnitude

One variable that has been found to alter delay discounting is reinforcer magnitude. For instance, it has been consistently found in humans that larger reinforcers are discounted less than smaller reinforcers (i.e., magnitude effect) when using both real (Kirby, 1997) and hypothetical reinforcers (Green, Fry, & Myerson, 1994; Johnson & Bickel, 2002). However, non-human animal studies using adjusting-amount delay-discounting procedures (described below) similar to the procedure used with humans have had mixed results with regard to the magnitude effect with some being unsuccessful in replicating the effect (Green, Myerson, Holt, Slevin, & Estle, 2004; Richards, Mitchell, de Wit, & Seiden, 1997) and others providing support for it (Wade, de Wit, & Richards, 2000).

Richards, Mitchell, de Wit, and Seiden (1997) examined the magnitude effect in rats using an adjusting-amount procedure similar to the procedure used in human studies. In their procedure, choice was between a smaller, immediate amount of water and a larger, delayed amount of water (100 μ L or 200 μ L depending on the condition). Depending on choice, the smaller amount of water was increased or decreased until choice for both options was approximately equal. They found that reinforcer magnitude did not alter discounting rates. Similarly, Green, Myerson, Holt, Slevin, and Estle (2004) used the same adjusting-amount

procedure with pigeons and rats, but used food as the reinforcer and a wider range of amounts (i.e., 5, 12, 20, 32 food pellets), and also found that rates of delay discounting were similar, regardless of reinforcer magnitude. However, Wade, de Wit, and Richards (2000) found that large reinforcer choice increased when reinforcer magnitude increased. Using an adjusting-amount procedure with rats, choice was between a smaller, immediate amount of water and a larger, delayed amount of water (75 μ L, 150 μ L, or 300 μ L depending on condition). It was found that rates of delay discounting were significantly lower (i.e., decreased impulsive choice) when the reinforcer magnitude was 300 μ L of water, compared to 75 μ L of water.

The magnitude effect has also been evaluated using a concurrent-chains procedure (e.g., Grace, 1999; Logue & Chavarro, 1987; Ong & White, 2004). In the typical concurrent-chains procedure, responding during one of two initial-link variable-interval (VI) schedules allows access to one of two terminal-link fixed-time (FT) schedules. In other words, the first response after an average amount of time (VI component) results in reinforcement after a fixed delay (FT component). The initial-link schedules are the same, but the terminal-link schedules differ in duration, so that effects of delay on relative response rate can be identified. Either separately or in addition to the change in delay (FT component), reinforcement magnitudes associated with terminal-link schedules can also be altered.

Using a concurrent-chains procedure with pigeons, Logue and Chavarro (1987) kept the relative reinforcer ratios the same, but changed the absolute reinforcer-magnitude difference across several sessions and found that relative response rate in the initial link associated with the larger reinforcer decreased as the absolute size of the reinforcer increased. In other words, they found a magnitude effect, but the effect was opposite of that reported in the human literature.

Also, they concluded that their results were not consistent with the Matching Law, which states that relative response rate is proportional to relative reinforcement rate (Herrnstein, 1970).

Anderson and Woolverton (2003) used a discrete-trials procedure, where rhesus monkeys chose between a smaller, more immediate and a larger, more delayed dose of cocaine, where the delay associated with the larger reinforcer was systematically increased. Keeping the ratio difference the same between the smaller and larger cocaine dose, the absolute values of each were increased. Although choice for the larger reinforcer decreased as delay increased (i.e., delay discounting), there were no differences observed between the two magnitude conditions. In other words, the results were consistent with the Matching Law.

Overall, results are mixed with regard to what effect reinforcer magnitude has on delay discounting, and it is unclear the degree to which the absolute difference in reinforcer magnitude influences choice in a delay-discounting context. Therefore, the purpose of Experiment 1 was to examine effects of the absolute magnitude difference between the smaller, immediate and larger, delayed reinforcers on delay discounting using a discrete-trials procedure.

Delay Discounting and *d*-Amphetamine

Increased rates of delay discounting have been correlated with substance abuse (Bickel, Odum, & Madden, 1999; Kirby, Petry, & Bickel, 1999; Madden, Petry, Badger, & Bickel, 1997). However, the relation between substance abuse and delay discounting is unclear. For instance, it is possible that increased rates of delay discounting (i.e., increased impulsive choice) underlie substance abuse, that substance abuse underlie increased rates of delay discounting, or that other variables underlie both increased rates of delay discounting and substance abuse. While it is possible to examine acute effects of drugs on delay discounting using humans, which many have done (e.g., Acheson, Reynolds, Richards, de Wit, 2006; de Wit, Enggasser, & Richards, 2002;

McDonald, Schleifer, Richards, & de Wit, 2003), animal studies allow for better control of behavioral and genetic histories, which may confound human study results.

d-Amphetamine (*d*-AMP) is a widely abused stimulant-class drug (Jupp & Lawrence, 2010), and is commonly used to treat ADHD, a disorder characterized by impulsive behavior (American Psychiatric Association, 2000; Spencer, Biederman, Wilens, & Faraone, 2002). Therefore, understanding effects of *d*-AMP on impulsive choice is important. Many have examined effects of *d*-AMP on delay discounting, but the results have been mixed. For instance, some studies have found that *d*-AMP decreased rates of delay discounting (van Gaalen, van Koten, Schoffelmeer, & Vanderschuren, 2006; Wade, de Wit, & Richards, 2000; Winstanley, Dalley, Theobald, & Robbins, 2003), while others have found that *d*-AMP increases rates of delay discounting. (Evenden & Ryan, 1996; Hand, Fox, & Reilly, 2009; Slezak & Anderson, 2008).

One reason for the discrepant findings with *d*-AMP could be due to procedural variations. For instance, Evenden and Ryan (1996), using rats, found that *d*-AMP increased rates of delay discounting using a discrete-trials procedure with rats, where choice was between a smaller, immediate and larger, delayed reinforcer, and the delay associated with the larger reinforcer was systematically increased during the session. Also, using a discrete-trials procedure based on that developed by Evenden and Ryan, Slezak and Anderson (2008), using rats, found that large doses of *d*-AMP increased rates of delay discounting using rats. However, Wade, de Wit, and Richards (2000) found that *d*-AMP decreased rates of delay discounting using an adjusting-amount procedure with rats, where choice was between a smaller, immediate reinforcer and a larger, delayed reinforcer, and the smaller, immediate reinforcer amount was adjusted based on choice.

Another potential reason for the discrepant findings could have to do with the fact that in delay-discounting procedures, both reinforcer delay and amount are manipulated. Therefore, it cannot be directly determined whether *d*-AMP is altering sensitivity to delay, sensitivity to amount, sensitivity to both, or some other variable. For instance, if *d*-AMP reduces sensitivity to delay, it would be expected that choice for the larger reinforcer would increase. However, if *d*-AMP decreases sensitivity to amount, it would be expected that choice for the larger reinforcer would decrease (Maguire, Rodewald, Hughes, & Pitts, 2009; TA, Pitts, Hughes, McLean, & Grace, 2008).

Maguire et al. (2009), using pigeons, found that *d*-AMP decreased sensitivity to reinforcer amount, while TA et al. (2008), using pigeons, found that *d*-AMP decreased sensitivity to reinforcer delay. Maguire et al. argued that *d*-AMP might alter both sensitivity to delay and amount the same proportionally. Therefore, whichever parameter is higher during baseline would be changed most by *d*-AMP. For instance, if sensitivity to delay was higher than sensitivity to amount during baseline (i.e., higher delay discounting), sensitivity to delay would be reduced most by *d*-AMP, resulting in a decrease in delay discounting. It would be predicted, then, that *d*-AMP would increase delay discounting when lower rates of delay discounting are observed at baseline, and decrease delay discounting when higher rates of delay discounting are observed at baseline. This prediction was supported by a recent study by Perry, Stairs, and Bardo (2008).

Perry, Stairs, and Bardo (2008) tested effects of *d*-AMP on delay discounting using an adjusting-delay procedure, where choice was between a smaller, immediate and larger, delayed reinforcer, and the delay associated with the larger reinforcer was adjusted based on choice. Before beginning the experiment, rats were divided into either an environmental-enrichment

condition or isolated condition. Rats in the environmental-enrichment condition were housed together and had toys placed in their home cage, whereas rats in the isolated condition were housed alone and were not given toys. Rats in the isolated condition had higher rates of delay discounting than those in the enrichment condition, and *d*-AMP decreased delay discounting for rats in the isolated condition, and increased delay discounting for rats in the enriched condition. Therefore, the baseline rate of delay discounting changed effects *d*-AMP had on delay discounting. Although it cannot be directly determined what effect *d*-AMP had on sensitivity to reinforcer delay/amount, it does show that baseline rates of discounting can alter effects of *d*-AMP on delay discounting. Because reinforcer magnitude has been shown by some to alter baseline levels of delay discounting, the purpose of Experiment 2 was to test whether *d*-AMP would differentially affect delay discounting when the absolute-magnitude difference between the smaller, immediate and larger, delayed reinforcers was changed.

Statement of the Problem

Evenden and Ryan's (1996) discrete-trials procedure is commonly used for evaluating delay discounting and effects of parametric manipulations on delay discounting. One parameter that has been shown to alter discounting rates reliably with humans is reinforcer amount, although results from the non-human literature have been mixed. Also, it is unclear the degree to which absolute reinforcer magnitude influences choice in a delay-discounting context.

The purpose of Experiment 1 was to use a discrete-trials procedure to compare delay discounting when the absolute, but not relative, magnitude difference in reinforcement was altered. Specifically, in the Small-Magnitude (SM) Condition, choice was between one immediate and three delayed food pellets, while in the Large-Magnitude (LM) Condition, choice was between two immediate and six delayed food pellets. Therefore, the relative difference

between the smaller and larger reinforcers was identical in the two conditions (i.e., three to one ratio). However, the absolute difference between smaller and larger reinforcers was two food pellets in the SM Condition and four food pellets in the LM Condition. It was hypothesized that rates of delay discounting would be lower in the LM Condition compared to the SM Condition.

d-AMP has been shown to alter delay discounting, although the results have been mixed. Perry, Stairs, and Bardo (2008) showed that effects of *d*-AMP differed based on baseline rates of delay discounting. As reinforcer magnitude has been found to alter baseline rates of delay discounting, it is possible that *d*-AMP will have different effects based on the magnitude difference between the smaller, more immediate reinforcer and the larger, delayed reinforcer. Therefore, the purpose of Experiment 2 was to test whether *d*-AMP had different effects, based on the reinforcer magnitude condition. It was hypothesized that *d*-AMP would decrease rates of delay discounting in the SM Condition, and would increase rates of delay discounting in the LM Condition.

Experiment 1

The purpose of Experiment 1 was to use a discrete-trials procedure to compare delay discounting when the absolute, but not relative, magnitude difference in reinforcement was altered. Based on the results from the human literature showing that rates of delay discounting are lower for larger reinforcers, compared to smaller reinforcers, it was hypothesized that rates of delay discounting would be lower in the LM Condition compared to the SM Condition. The relative magnitude difference between smaller and larger reinforcers was the same in the LM and SM conditions (i.e., three to one ratio); however, the absolute magnitude difference was different in the two conditions (two food pellets and four food pellets, respectively).

Method

Subjects

Seven experimentally naïve Sprague-Dawley rats were used. Originally, eight rats were part of the study, but one animal was dropped from the study due to an inability to obtain stable delay discounting. Rats were housed individually in an Animal Care and Use Committee (ACUC) approved facility at West Virginia University, and all procedures used throughout the study were ACUC approved. The colony room was maintained at approximately 21-27° C and a 12-hr reverse light-dark schedule was implemented. Rats were allowed *ad libitum* access to water. Rats were fed 30 min after each experimental session, resulting in approximately 22-hr food restriction at the beginning of each experimental session.

Apparatus

Sessions were conducted in seven standard operant-conditioning chambers for rats, each enclosed in a melamine sound-attenuating cubicle (Med Associates, VT). Each chamber contained a working area of 30.5 cm by 24.1 cm by 21.0 cm, a grid floor, and a 45-mg pellet dispenser with a pellet receptacle centered between two retractable response levers, which were 11.5 cm apart from each other, requiring at least 0.25 N for a response to be recorded, were 4.8 cm wide, protruded 1.9 cm into the chamber, and were elevated 8 cm from the grid floor. Two 28-V stimulus lights of 2.5 cm in diameter were placed approximately 7 cm above each lever. Each chamber had a 28-V houselight on the wall opposite to the wall containing the levers and a ventilation fan to circulate air and to mask extraneous noise. Equipment was interfaced to a computer and routines were programmed and conducted with MedPC-IV (Med Associates, VT). Forty-five mg grain food pellets were used as reinforcers in the present study.

Procedure

Initial Training. Lever pressing was trained using a delay-to-reinforcement procedure during an 8-hr session. During this session, lever pressing was reinforced according to a tandem fixed-ratio (FR) 1 FT 20-s schedule, where one lever press resulted in the delivery of either one (half of subjects) or three (half of subjects) food pellets after a 20-s non-resetting delay. After the delay-to-reinforcement procedure, a conjoint FR 1 variable-time (VT) 60-s schedule was in effect, where one food pellet was delivered after either a single lever press or after an average of 60 s had elapsed. Values for the VT were obtained using a Fleshler-Hoffman sequence generator for 20 cycles of reinforcer delivery. Once all food pellets were obtained by lever-pressing, lever-pressing was reinforced according to an FR 1 schedule that alternated between the left and right levers every five food presentations, with sessions ending after 40 food presentations. For rats that did not acquire lever-pressing, lever-pressing was reinforced by successive approximations followed by the alternating procedure described above.

Delay-Discounting Procedure. A discrete-trials delay-discounting procedure similar to Evenden and Ryan's (1996) procedure was used in the current study. Each session was divided into five blocks of eight trials, with each block beginning with two forced-choice trials followed by six free-choice trials. The delay associated with one lever was always 0 s, while the delay associated with the other lever was systematically increased across blocks (e.g., 0, 5, 10, 20, 40 s). Prior to the first trial, a 10-min blackout was in effect, where all lights within the chamber were darkened. Trials began every 100 s, resulting in a variable inter-trial interval (ITI). The first two trials in each block were forced-choice trials, which were used to ensure exposure to contingencies associated with each lever before allowing for choice between the two levers.

Forced-choice trials began with either the left or right lever (randomly determined) extending, illumination of the houselight, and illumination of the stimulus light. The lever associated with the larger reinforcer (three or six food pellets, depending on condition) was counterbalanced across animals within each group. If a response was emitted on the lever associated with the larger reinforcer, the lever retracted, the stimulus light above the operative lever extinguished, and after the delay period, the houselight blinked once every 0.1 s as each food pellet was delivered. This was followed by a blackout that was in effect until the next trial began. If a response was not made within 30 s of trial starting, the operative lever retracted, all chamber lights darkened, and the response was recorded as an omission. When a response was made on the lever associated with the immediate reinforcer, all consequences were the same, except there was no delay between the levers retracting, stimulus light going off, and the houselight blinking. If a response was not made within 30 s of the trial starting, the operative lever retracted, all chamber lights darkened, and the response was recorded as an omission.

The last six trials in each block were free-choice trials, where both left and right levers extended, and a response on either lever resulted in immediate or delayed reinforcement, depending on the condition associated with each lever. The lever associated with the larger reinforcer was the same as in the forced-choice trial. Consequences following a lever press were the same during the free-choice trials as in the forced-choice trials. If a response was not made within 30 s of the trial starting, both levers retracted, all chamber lights darkened, and the response was recorded as an omission.

All rats started with an 8-s terminal-delay sequence, where the delay associated with the larger reinforcer progressively increased across blocks (i.e., 0, 1, 2, 4, 8 s). The terminal delay was increased if choice for the larger reinforcer was more than 50% in each block across the last

five sessions. The terminal delay sequence was increased until intermediate discounting functions were obtained or until the maximum terminal delay sequence of 60 s. The progression of delay sequences was 8 s (listed above), 16 s (0, 2, 4, 8, 16 s), 40 s (0, 5, 10, 20, 40), and 60 s (0, 10, 20, 40, 60 s). The 60-s terminal-delay sequence was used for all rats.

All rats experienced SM and LM conditions according to an ABA design. However, three rats started with the LM Condition, and four rats started with the SM Condition (see Table 1). Prior to the first magnitude condition listed in Table 1, rats starting with the SM Condition had experience with the LM Condition, while rats starting with the LM Condition had experience with the SM Condition. This was done because the initial plan was to alternate the lever associated with the larger reinforcer between magnitude conditions. However, after switching the lever associated with the larger reinforcer between the first and second condition for all rats, strong lever biases were present for some rats on the new lever associated with the larger reinforcer. This may have been a result of starting the new magnitude condition with 0-s probe sessions (described below), where the delay associated with the larger reinforcer was 0 s across all blocks of trials. These 0-s probe sessions were continued until percent larger-reinforcer choice was at least 80% in each block. Because of apparent biases seen by some rats, future magnitude conditions were conducted without changing the lever associated with the larger reinforcer, and the first magnitude condition was excluded from analyses.

Stability criteria. Stability criteria included at least 20 sessions being conducted and, across the last five sessions, at least 80% large reinforcer choice during the 0-s delay block, no observed bounce or trends across days in any blocks, and no more than a 20% deviation in total larger- reinforcer choice across sessions.

Table 1

Sequence of reinforcer-magnitude conditions for each rat (Small-Magnitude Condition = SM, Large-Magnitude Condition = LM)

Subject	First Condition	Second Condition	Third Condition
WR-3	SM	LM	SM
WR-4	SM	LM	SM
WR-7	SM	LM	SM
WR-8	SM	LM	SM
WR-1	LM	SM	LM
WR-2	LM	SM	LM
WR-5	LM	SM	LM

Zero-second probes. To assess sensitivity to reinforcer amount, 0-s probe sessions were conducted once every two weeks. During these sessions, the delay to the larger reinforcer was 0 s across all blocks. Because choice was between a smaller, immediate reinforcer and a larger, immediate reinforcer, it was expected that choice would be maintained by the larger reinforcer across all blocks. Therefore, these sessions were repeated, if necessary, until percent larger-reinforcer choice was at least 83% (5 out of 6) in the first block, at least 83% in three out of the four subsequent blocks, and no more than one block where choice was 67% (4 out of 6).

Data analysis. Mean percent larger-reinforcer choice across the various delay values were calculated for each subject. AUC was calculated by normalizing the delay values, plotting percent-large-reinforcer choice as a function of delay, dividing the plot into trapezoids, summing the trapezoids, and dividing the sum by the total area of the graph. AUC values range from 0 to 1, with higher numbers corresponding to lower rates of delay discounting (less impulsive choice). AUC is considered an objective way of assessing delay-discounting functions (Myerson, Green, and Warusawithrana, 2001). The number of sessions required before stability criteria were met, the number of sessions required to pass 0-s probe sessions, and AUC in the averaged initial and reversal SM conditions and initial and reversal LM conditions were compared via paired-samples t-tests. Percent larger-reinforcer choice across delay blocks in the averaged SM and averaged LM conditions was compared via a 2 X 5 repeated-measures ANOVA with reinforcer-magnitude condition (SM or LM) and delay to the larger reinforcer (0, 10, 20, 40, 60 s) as within-subject variables.

Results

Stability

Table 2 shows the number of sessions required to meet stability criteria across each magnitude condition for all rats. With the exception of WR-8, fewer sessions were required to meet stability criteria in the replicated conditions (SM or LM Reversal Condition, depending on animal), compared to the initial conditions (SM or LM Condition, depending on animal), though the differences were not statistically significant at the group level. With the exception of WR-2 in the first SM Condition, fewer sessions were required to meet stability criteria in the SM and SM Reversal conditions, compared to the LM and LM Reversal conditions. The number of days required to meet stability criteria in the SM and SM Reversal conditions were combined and compared to the combined number of days required in the LM and LM Reversal conditions. More sessions were required to meet stability criteria in the SM conditions, compared to the LM conditions, and across rats, this difference was statistically significant, $t(6) = 2.75, p = .03$.

0-s probe sessions

Table 3 shows the average number of 0-s probe sessions required in each reinforcer magnitude condition. With the exception of WR-8 and WR-2, more 0-s probe sessions were required in the SM conditions, compared to the LM conditions. However, the difference between the average number of 0-s probe sessions required in the initial and reversal SM conditions, compared to the initial and reversal LM conditions was not statistically significant across rats.

Delay discounting

As shown by Figure 1, percent larger-reinforcer choice decreased as delay to the larger reinforcer increased for all rats in both the SM and LM conditions. For rats starting with the SM Condition (left panels), both SM and SM Reversal conditions resulted in higher rates of delay

Table 2

Number of sessions required to meet stability criteria in the Small-Magnitude Condition (SM), Large-Magnitude Condition (LM), reversal of the Small-Magnitude Condition (SM Reversal), and reversal of the Large-Magnitude Condition (LM Reversal). SM Combined represents the averages of the combined SM and SM Reversal conditions, and LM Combined represents the averages of the combined LM and LM Reversal conditions. The single asterisk represented statistically significant difference in sessions required between the SM Combined and LM Combined conditions at $p < .05$.

Subject	Starting	SM		LM		SM	LM
	Condition	SM	LM	Reversal	Reversal	Combined	Combined
WR-3	SM	44	20	25	-	34.5	20
WR-4	SM	39	20	21	-	30	20
WR-7	SM	60	34	44	-	52	34
WR-8	SM	25	20	27	-	26	20
WR-1	LM	72	22	-	21	72	21.5
WR-2	LM	29	34	-	20	29	27
WR-5	LM	81	30	-	20	81	25
<i>M</i>	-	50.00	25.71	29.25	20.33	46.36*	23.93
<i>SEM</i>	-	8.12	2.52	5.07	0.33	8.47	1.98

Table 3

Mean number of 0-s probe sessions required in the Small-Magnitude Condition (SM), Large-Magnitude Condition (LM), reversal of the Small-Magnitude Condition (SM Reversal), and reversal of the Large-Magnitude Condition (LM Reversal). SM Combined represents the averages of the combined SM and SM Reversal conditions, and LM Combined represents the averages of the combined LM and LM Reversal conditions

Subject	Starting	SM		LM	SM		LM
	Condition	SM	LM	Reversal	Reversal	Combined	Combined
WR-3	SM	1.33	1.00	1.50	-	1.42	1.00
WR-4	SM	1.67	1.00	1.00	-	1.33	1.00
WR-7	SM	4.67	1.00	8.00	-	6.34	1.00
WR-8	SM	1.00	1.00	1.00	-	1.00	1.00
WR-1	LM	3.00	1.00	-	1.00	3.00	1.00
WR-2	LM	1.50	3.00	-	1.00	1.50	2.00
WR-5	LM	3.80	1.33	-	1.00	3.80	1.17
<i>M</i>	-	2.42	1.33	2.88	1.00	2.63	1.17
<i>SEM</i>	-	0.53	0.28	1.71	0.00	0.73	0.14

Figure 1. Percent larger-reinforcer choice as a function of delay to the larger reinforcer in the Small-Magnitude Condition (SM), Large-Magnitude Condition (LM), SM-Reversal Condition (SM Reversal), and LM-Reversal Condition (LM Reversal) for subjects that started with the SM Condition (left panel) and LM Condition (right panel). Error bars represent ± 1 standard error of the mean.

discounting, compared to the LM Condition. Similarly, for rats starting with the LM Condition (right panels), both LM and LM Reversal conditions resulted in lower rates of delay discounting, compared to the SM Condition. Because consistently lower rates of delay discounting were observed in the LM Condition(s), compared to the SM Condition(s) across all rats, percent larger-reinforcer choice and AUC in SM and SM Reversal conditions were combined and LM and LM Reversal conditions were combined for statistical analyses. Figure 2 shows percent larger-reinforcer choice across delay blocks (upper panel) and AUC (bottom panel) in the combined SM and LM conditions. Across all rats, degree of delay discounting was greater in the combined SM conditions, compared to the LM conditions. This was supported by the results of a 2 X 5 repeated measures ANOVA, which showed a significant magnitude condition X delay block interaction, $F(1.82, 10.89) = 7.34, p = .011$. Specifically, percent larger-reinforcer choice was significantly lower in the 20 ($p = .033$), 40 ($p = .002$), and 60-s delay blocks ($p < .001$), compared to the 0-s delay block in the combined SM conditions, while percent larger-reinforcer choice did not significantly differ across delay blocks in the combined LM conditions. Similarly, AUC was significantly lower in the combined SM conditions ($M = .52, SD = .28$), compared to the combined LM conditions ($M = .90, SD = .12$), $t(6) = -4.09, p = .006$.

Discussion

In both the SM and LM conditions, as the delay to the larger reinforcer was increased, choice for the larger reinforcer decreased, which is consistent with past research (e.g., Anderson & Diller, 2010; Evenden & Ryan, 1996; Slezak & Anderson, 2008; Slezak & Anderson, 2011). Rates of delay discounting, however, were lower in the LM Condition, compared to the SM Condition, showing that reinforcer magnitude can alter rates of delay discounting. This result is consistent with past research that has shown that increasing the size of the larger, more delayed

Figure 2. Percent larger-reinforcer choice as a function of delay to the larger reinforcer (top panel) and area under the curve (AUC) averaged across subjects ($N = 7$) in the averaged initial and reversal Small-Magnitude conditions (SM) and averaged initial and reversal Large-Magnitude conditions (LM). Numbers represent individual rats. Error bars represent ± 1 standard error of the mean. Single, double, and triple asterisks represent statistically-significant differences in percent larger-reinforcer choice compared to the 0-s delay block in the SM Condition at $p < .05$, $.01$, and $.001$, respectively. The double number sign represents statistically-significant differences in AUC between the SM and LM conditions at $p < .01$

reinforcer magnitude decreases rates of delay discounting (e.g., Green, Fry, & Myerson, 1994; Johnson & Bickel, 2002; Kirby, 1997; Wade, de Wit, & Richards, 2000), but is inconsistent with studies using rats and pigeons that have shown that reinforcer magnitude does not alter delay discounting (i.e., Green, Myerson, Holt, Slevin, & Estle, 2004; Richards, Mitchell, de Wit, & Seiden, 1997).

One reason for the discrepant findings could be procedural differences between the current study and previous studies. For instance, Green, Myerson, Holt, Slevin, & Estle (2004) using rats and pigeons and Richards, Mitchell, de Wit, & Seiden (1997) using rats employed adjusting-amount procedures, and did not see an effect of reinforcer magnitude, while the present study employed a discrete-trials procedure. However, studies examining effects of reinforcer magnitude using humans have used similar adjusting-amount procedures, and have found reliable effects of reinforcer magnitude consistent with the present study's results (see Green & Myerson, 2004 for review). Furthermore, Wade, de Wit, and Richards (2000) used an adjusting-amount procedure with rats, and found an effect of reinforcer magnitude. Therefore, it is unlikely that procedural differences alone can account for the discrepant findings.

Another possible reason for the discrepant findings could have to do with the reinforcer magnitudes that were examined. For instance, the larger-reinforcer sizes compared in the present study were three and six 45-mg grain-based food pellets. Green, Myerson, Holt, Slevin, and Estle (2004), used five, ten, and twenty 20-mg food pellets (type unknown) across magnitude conditions. Though the five and ten 20-mg food-pellet conditions were similar (in terms of amount) to the three and six 45-mg food-pellet conditions, the number of pellets were higher, and the twenty 20-mg food pellet condition was much higher in terms of amount, compared to the present study.

Another important aspect to the present study's results is that the difference between the smaller and larger reinforcer varied across conditions. That is, the ratio difference in reinforcement was the same in the SM and LM conditions, while the absolute difference in reinforcer magnitudes was altered. Using an adjusting amount procedure, it is not possible to examine effects of the contrast between reinforcer amounts. This is because the difference between the smaller and larger reinforcer is altered throughout each session based on choice in an adjusting-amount procedure. It is possible, therefore, that the results in the present study were due to the contrast between the reinforcer magnitudes and not the size of the larger reinforcer.

Although the present study did show that rates of delay discounting were lower in the LM Condition, compared to the SM Condition, it is not possible to determine whether this effect was due to the difference in size of the larger reinforcer or the size of the difference between the smaller and larger reinforcers. One way to address this question would be to add an additional magnitude condition where choice was between four immediate and six delayed food pellets. In this case, the size of the difference between the smaller and larger reinforcer would be two (same as SM Condition), but the size of the larger reinforcer would be six (same as LM Condition). If choice was similar to the SM Condition, it would provide support that the size of the magnitude difference was the controlling variable, whereas if choice was similar to the LM Condition, it would provide support that the size of the larger reinforcer was the controlling variable.

Another finding of the present experiment was that more sessions were required to meet stability criteria in the SM conditions, compared to the LM conditions across all subjects. The main reason for this difference was because of low discounting rates in the LM conditions, relative to the SM conditions. The near-ceiling effect in discounting rates resulted in lower variability between sessions, and thus fewer sessions required to reach stability. It is unclear if

the same difference would have been observed if more intermediate delay-discounting functions had been observed in the LM Condition. For example, it is possible that if the terminal-delay sequence had been increased beyond 60 s in the LM Condition to where AUC values were comparable to the SM Condition, a similar number of sessions would have been required in both conditions.

Finally, the present study found that more 0-s probe sessions were required in the SM conditions, compared to the LM conditions for all rats except WR-2 and WR-8. This difference was likely because of the difference between the two magnitude conditions in terms of the absolute-magnitude difference between the smaller and larger reinforcer. As the absolute difference between the smaller and larger reinforcers was larger in the LM Condition, compared to the SM Condition, the larger reinforcer likely had greater control over choice, resulting in fewer required 0-s probe sessions.

Experiment 2

The purpose of Experiment 2 was to test whether *d*-AMP would have different effects, as a result of the reinforcer-magnitude condition. Based on research showing that baseline rates of delay discounting determine effects of *d*-AMP on delay discounting (e.g., Perry, Stairs, and Bardo, 2008), it was hypothesized that *d*-AMP would decrease delay discounting in the SM Condition, and would increase delay discounting in the LM Condition.

Method

Subjects

The same seven rats used in Experiment 1 served as subjects in Experiment 2.

Apparatus

The same seven standard operant-conditioning chambers that were used in Experiment 1 were used in Experiment 2.

Procedure

Delay-discounting procedure. The same procedure that was used in Experiment 1 was used for Experiment 2.

Drug administration. *d*-AMP solution was prepared by dissolving *d*-AMP sulfate salt in 0.9% sodium chloride (1 mg/ml) and had an injection volume 1 mg/kg. After stability in the final reinforcer-magnitude condition was met, drug or saline (i.e., 0.9% sodium chloride) was injected intraperitoneally immediately before the 10-min blackout period at the start of the session on Tuesdays and Fridays if choice in the 0-s block was at least 80% during the session on the control days (i.e., Monday and Thursday, respectively), and percent-larger reinforcer choice was similar to that observed during the baseline condition. Prior to testing effects of *d*-AMP, at least two saline determinations were conducted to control for the injection procedure. Percent larger-reinforcer choice was examined after these two sessions to ensure that choice was comparable after saline was administered, compared to control sessions. More than two saline determinations were conducted if percent larger-reinforcer choice after saline systematically differed that observed during control days.

After the saline determinations, 0.1, 0.3, 1.0, and 1.8 mg/kg doses of *d*-AMP were presented in an ascending sequence for half of the rats (WR-5 through WR-8) and a descending sequence for half of the rats (WR-1 through WR-4), and at least two determinations of each dose were obtained. More than two determinations of a given dose were administered if the two determinations of a dose resulted in a deviation of more than three larger-reinforcer choices

across two or more delay blocks or if one determination resulted in fewer than five larger-reinforcer choices in the 0-s block, while the other determination resulted in five or six larger-reinforcer choices. During determinations of the dose-response function, if a dose suppressed responding (resulted in more than six response omissions) or if percent larger-reinforcer choice in the 0-s block was less than 83%, no higher doses were administered. Some rats required a 3.0 mg/kg dose of *d*-AMP because the 1.8 mg/kg dose did not suppress responding and percent larger-reinforcer choice was above 83%.

Data analysis. Because different doses of *d*-AMP were maximally effective in altering larger-reinforcer choice for some rats, AUC after saline and after the maximally effective dose of *d*-AMP (resulted in largest change from saline) were compared using a 2 X 2 mixed ANOVA with dose (saline or *d*-AMP) as a within-subject factor and reinforcer-magnitude condition (SM or LM) as a between-subjects factor. Dose determinations that resulted in more than six response omissions, or in which percent larger-reinforcer in the 0-s delay block was less than an average of 80% across determinations were not included in data analysis.

Results

Table 4 shows effects of *d*-AMP on percent larger-reinforcer choice and AUC for rats in the SM Condition. At least one dose of *d*-AMP decreased rates of delay discounting (increased AUC) across all rats, although the dose that was maximally effective differed across rats. Bolded values in Table 4 correspond to the dose of *d*-AMP that resulted in the largest change in AUC, compared to saline without reducing percent larger-reinforcer choice below 80% in the 0-s delay block. The highest dose of *d*-AMP tested either reduced percent larger-reinforcer choice below 80% in the 0-s delay block or resulted in response omissions for all four rats, making interpretations of effects of this dose on delay discounting difficult to interpret.

Table 4

Mean percent larger-reinforcer choice and area under the curve (AUC) after various doses of d-Amphetamine (Dose) for Rats in the Small-Magnitude Condition with standard error of the means in parentheses. The number of determinations for each dose are in parentheses. Bolded values indicate the dose of d-amphetamine that resulted in the largest change in AUC, relative to saline.

Subject	Dose	Percent Larger-Reinforcer Choice					AUC
		0-s	10-s	20-s	40-s	60-s	
WR-3	Saline (4)	100 (0)	92 (8)	63 (4)	33 (7)	25 (11)	0.55 (0.04)
	0.1 mg/kg (3)	100 (0)	72 (20)	72 (11)	22 (15)	33 (10)	0.53 (0.08)
	0.3 mg/kg (3)	100 (0)	94 (6)	33 (19)	33 (17)	33 (10)	0.49 (0.09)
	1.0 mg/kg (2)	92 (8)	92 (8)	75 (25)	42 (25)	92 (8)	0.85 (0.02)
	1.8 mg/kg (5)	93 (4)	57 (23)	43 (23)	27 (19)	17 (13)	0.40 (0.17)
	3.0 mg/kg (2)	_a	_a	_a	_a	_a	_a
WR-4	Saline (5)	100 (0)	96 (4)	79 (16)	47 (17)	25 (11)	0.60 (0.04)
	0.1 mg/kg (2)	100 (0)	92 (8)	92 (8)	25 (25)	8 (8)	0.57 (0.04)
	0.3 mg/kg (2)	100 (0)	92 (8)	100 (0)	67 (17)	50 (17)	0.79 (0.04)
	1.0 mg/kg (3)	89 (6)	61 (11)	33 (33)	39 (31)	11 (11)	0.41 (0.23)
	1.8 mg/kg (4)	71 (10)	71 (24)	54 (23)	0 (0)	8 (8)	0.33 (0.10)
WR-7	Saline (4)	92 (5)	25 (5)	0 (0)	4 (4)	0 (0)	0.13 (0.02)
	0.1 mg/kg (2)	100 (0)	25 (25)	0 (0)	0 (0)	0 (0)	0.13 (0.05)
	0.3 mg/kg (3)	94 (6)	44 (6)	17 (10)	6 (6)	0 (0)	0.22 (0.05)
	1.0 mg/kg (3)	67 (10)	61 (6)	11 (11)	0 (0)	0 (0)	0.19 (0.04)
	1.8 mg/kg (3)	50 (17)	33 (33)	17 (17)	0 (0)	0 (0)	0.15 (0.05)
WR-8	Saline (5)	97 (3)	97 (3)	97 (3)	30 (8)	27 (8)	0.63 (0.04)
	0.1 mg/kg (2)	92 (8)	92 (8)	100 (0)	67 (17)	33 (0)	0.76 (0.05)
	0.3 mg/kg (2)	100 (0)	100 (0)	100 (0)	92 (8)	42 (8)	0.88 (0.05)
	1.0 mg/kg (2)	92 (8)	100 (0)	100 (0)	83 (17)	50 (17)	0.85 (0.09)
	1.8 mg/kg (4)	63 (17)	67 (19)	42 (22)	33 (24)	29 (24)	0.43 (0.20)

^a Data were excluded because more than six response omissions occurred across all determinations.

Table 5 shows effects of *d*-AMP on percent larger-reinforcer choice and AUC for rats in the LM Condition. *d*-AMP increased rates of delay discounting (decreased AUC) for WR-1 and WR-2, but had no effect on rates of delay discounting for WR-5. Bolded values in Table 5 correspond to the dose of *d*-AMP that resulted in the largest change in AUC, compared to saline without reducing percent larger-reinforcer choice below 80% in the 0-s delay block. The highest dose of *d*-AMP tested did, however, either reduce percent larger-reinforcer choice below 80% in the 0-s delay block or resulted in response omissions for all three rats.

Figure 3 shows the across-subject average percent change from saline in AUC as a function of dose of *d*-AMP for rats in the SM Condition (open bars) and LM Condition (cross-hatched bars). Consistent with the results from individual rats, *d*-AMP generally increased AUC for rats in the SM Condition, and decreased AUC for rats in the LM. Although the 1.8 mg/kg dose of *d*-AMP decreased AUC for rats in both the SM and LM conditions, it should be noted that this dose reduced choice below 80% in the 0-s block for three out of four rats in the SM Condition (WR-4, WR-7, and WR-8) and two out of three rats in the LM Condition (WR-1 and WR-2). This disruption in discrimination of amount makes effects of *d*-AMP on delay discounting are difficult to interpret. Table 6 contrasts AUC across rats in each reinforcer-magnitude condition after receiving saline, compared to the dose of *d*-AMP that resulted in the greatest change from saline (most effective dose). The most effective dose of *d*-AMP increased AUC for all four rats in the SM Condition, and decreased AUC for two of the three rats in the LM Condition (WR-1 and WR-2). The 1.0 and 1.8 mg/kg doses of *d*-AMP resulted in an equally small increase in AUC, compared to saline for WR-5, though AUC after these doses of *d*-AMP did not differ from what was observed during control or baseline sessions. Overall, *d*-AMP differentially affected AUC, depending on reinforcer magnitude condition, which was supported

Table 5

Mean percent larger-reinforcer choice and area under the curve (AUC) after various doses of d-Amphetamine (Dose) for Rats in the Large-Magnitude Condition with standard error of the means in parentheses. The number of determinations for each dose are in parentheses. Bolded values indicate the dose of d-amphetamine that resulted in the largest change in AUC, relative to saline.

Subject	Dose	Percent Larger-Reinforcer Choice					AUC
		0-s	10-s	20-s	40-s	60-s	
WR-1	Saline (5)	97 (3)	97 (3)	93 (7)	80 (6)	80 (6)	0.88 (0.04)
	0.1 mg/kg (2)	100 (0)	100 (0)	100 (0)	75 (8)	58 (8)	0.85 (0.02)
	0.3 mg/kg (2)	92 (8)	100 (0)	92 (8)	67 (17)	58 (8)	0.84 (0.02)
	1.0 mg/kg (5)	80 (8)	73 (12)	57 (11)	47 (12)	43 (7)	0.56 (0.06)
	1.8 mg/kg (5)*	61 (11)	56 (20)	67 (25)	72 (6)	89 (6)	0.70 (0.07)
	3.0 mg/kg (2)	_a	_a	_a	_a	_a	_a
WR-2	Saline (6)	97 (3)	100 (0)	100 (0)	75 (11)	33 (15)	0.88 (0.05)
	0.1 mg/kg (3)	94 (6)	100 (0)	100 (0)	83 (17)	22 (15)	0.81 (0.08)
	0.3 mg/kg (2)	92 (8)	83 (17)	75 (8)	25 (8)	25 (8)	0.54 (0.02)
	1.0 mg/kg (3)	94 (6)	44 (15)	6 (6)	17 (0)	11 (6)	0.24 (0.04)
	1.8 mg/kg (3)	61 (20)	39 (31)	17 (17)	17 (17)	11 (6)	0.25 (0.16)
WR-5	Saline (4)	100 (0)	100 (0)	100 (0)	96 (4)	96 (4)	0.98 (0.02)
	0.1 mg/kg (3)	100 (0)	100 (0)	100 (0)	94 (6)	100 (0)	0.98 (0.02)
	0.3 mg/kg (3)	100 (0)	100 (0)	100 (0)	100 (0)	100 (0)	1.00 (0.00)
	1.0 mg/kg (3)	100 (0)	100 (0)	100 (0)	100 (0)	100 (0)	1.00 (0.00)
	1.8 mg/kg (3)	100 (0)	100 (0)	100 (0)	100 (0)	100 (0)	1.00 (0.00)
	3.0 mg/kg (2)	_a	_a	_a	_a	_a	_a

* Last two determinations were not included because more than six response omissions occurred.

_a Data were excluded because more than six response omissions occurred across all determinations.

Figure 3. Percent change from saline in area under the curve (AUC) during control sessions and after various doses of *d*-amphetamine for animals in the Small-Magnitude Condition (SM, open bars, $n = 4$) and the Large-Magnitude Condition (LM, cross-hatched bars, $n = 3$). Note that choice for the larger reinforcer in the 0-s block was less than 80% for three out of four rats in the SM Condition and two out of three rats in the LM Condition after the 1.8 mg/kg dose of *d*-amphetamine, making changes in AUC at that dose difficult to interpret. Standard error bars represent ± 1 standard error of the mean.

Table 6

Area Under the Curve After the Dose of d-Amphetamine that Resulted in the Largest Change in Area Under the Curve, Compared to Saline for Animals in the Small-Magnitude (SM) and Large-Magnitude (LM) Conditions. The single asterisk represents statistically significant difference in AUC, relative to saline at $p < .05$.

Subject	Most Effective Dose	<u>AUC</u>	
		Saline	d-Amphetamine
WR-3 (SM)	1.0 mg/kg	0.55 (0.04)	0.85 (0.02)
WR-4 (SM)	0.3 mg/kg	0.60 (0.04)	0.79 (0.04)
WR-7 (SM)	0.3 mg/kg	0.13 (0.02)	0.22 (0.05)
WR-8 (SM)	0.3 mg/kg	0.63 (0.04)	0.88 (0.05)
<i>M (SEM)</i>	-	0.48 (0.11)	0.69 (0.16)*
WR-1 (LM)	1.0 mg/kg	0.88 (0.04)	0.56 (0.06)
WR-2 (LM)	1.0 mg/kg	0.88 (0.05)	0.24 (0.04)
WR-5 (LM)	1.8 mg/kg	0.98 (0.02)	1.00 (0.00)
<i>M (SEM)</i>	-	0.91 (0.03)	0.60 (0.22)

by the results of a 2 X 2 repeated measures ANOVA, which showed a significant magnitude condition (SM or LM) X drug (saline or *d*-AMP) interaction, $F(1, 5) = 9.60, p = .027$.

Specifically, AUC after *d*-AMP was significantly higher, compared to saline for rats in the SM Condition ($p = .019$), but AUC did not significantly differ after *d*-AMP, compared to saline across rats in the LM Condition.

Discussion

The primary finding of Experiment 2 of the present study was that lower baseline rates of delay discounting were observed for rats in the LM Condition, compared to rats in the SM Condition (consistent with Experiment 1), and effects of *d*-AMP depended on reinforcer-magnitude condition. Specifically, *d*-AMP increased larger-reinforcer choice for rats in the SM Condition, and with the exception of WR-5, decreased larger-reinforcer choice for rats in the LM Condition. It is unclear why *d*-AMP did not alter delay discounting for WR-5; however, one possible reason could have to do with the degree of control the larger reinforcer maintained over choice in the LM Condition. For instance, near-exclusive choice was observed for the larger reinforcer in the LM Condition for WR-5. Previous studies have shown that behavior maintained by strong stimulus control is less easily disrupted by drug, compared to behavior maintained by weak stimulus control (e.g., Ksir, 1975; Laties, Wood, & Rees, 1981). Therefore, it is possible that *d*-AMP did not alter choice for WR-5 because of the high level of control the larger reinforcer maintained in the LM Condition. In support of this, in general, a higher dose of *d*-AMP was required to alter choice for rats in the LM Condition, compared to rats in the SM Condition. Specifically, the 0.3 mg/kg dose of *d*-AMP resulted in the largest change in larger-reinforcer choice for three of the four rats in the SM Condition, while the 1.0 mg/kg dose of *d*-AMP resulted in the largest change in larger-reinforcer choice for two of the three rats in the LM

Condition. Therefore, the results of the Experiment 2 do support previous studies' finding that behavior under stronger control is less easily disrupted by drug. Overall, however, these results are consistent with others' finding that baseline rates of delay discounting can determine effects of *d*-AMP on delay discounting (e.g., Barbelivien, Billy, Lazarus, Kelche, & Majchrzak, 2007; Perry, Stairs, & Bardo, 2008).

Although baseline rates of delay-discounting in this experiment and previous studies were successful in predicting effects of *d*-AMP on delay discounting, baseline rates cannot be used as an explanation for the differential effects observed. Reinforcer amount and reinforcer delay are two variables controlling choice in the delay-discounting procedures. Previous studies have shown that *d*-AMP alters both sensitivity to reinforcer amount (Maguire, Rodewald, Hughes, & Pitts, 2009) and sensitivity to reinforcer delay using concurrent-chains procedures (TA, Pitts, Hughes, McLean, & Grace, 2008). Maguire, Rodewald, Hughes, and Pitts proposed that *d*-AMP disrupts sensitivity to delay and sensitivity to reinforcer amount the same amount proportionally, so the parameter higher during baseline would be disrupted to a greater degree.

Unfortunately, delay-discounting procedures cannot separate effects on sensitivity to delay from sensitivity to amount. However, reduction in sensitivity to delay would result in a decrease in delay discounting, while reduction in sensitivity to amount would result in an increase in delay discounting. The present study found that when baseline rates of delay discounting were relatively low (LM Condition), *d*-AMP generally increased rates of delay discounting, consistent with a decrease in sensitivity to amount. Conversely, when baseline rates of delay discounting were relatively high (SM Condition), *d*-AMP decreased rates of delay discounting, consistent with a decrease in sensitivity to delay. Therefore, it is possible that the parameter with greater relative control over choice (reinforcer amount or reinforcer delay) is

disrupted more by *d*-AMP. If this is the case, it may be difficult to predict effects of *d*-AMP when intermediate delay discounting is observed because it is unclear whether choice is controlled more by amount or delay. One way to test this hypothesis could be to generate different rates of delay discounting, and test effects of *d*-AMP under each condition.

Although the hypothesis is consistent with the general results found in the present study, it does not account for the finding that the 1.8 mg/kg dose increased delay discounting for rats in the SM Condition. However, it is important to note that this dose reduced choice for the larger reinforcer below 80% for three of the four rats in the SM Condition and two of the three rats in the LM Condition, making effects on delay discounting difficult to interpret. While a reduction in sensitivity to amount would be consistent with the reduction in larger-reinforcer choice in the 0-s delay block, it is also possible that the dose altered response bias. Overall, the results from the present experiment show that baseline rate of delay discounting is an important variable to consider when examining effects of *d*-AMP on delay discounting. Furthermore, the mechanism behind different effects may lie in which sensitivity parameter is altered to a greater degree by *d*-AMP, and may be a possible reason for the discrepant findings seen with regard to effects of *d*-AMP on delay discounting.

Summary and General Discussion

Overall, the present study showed that increasing the absolute magnitude difference between the smaller, more immediate and larger, more delayed reinforcers, while keeping the relative difference the same, increased choice for the larger, delayed reinforcer in a delay-discounting context. However, it is not possible to determine whether the difference between the SM and LM conditions was due to the difference between the smaller and larger reinforcer or if it was due to the size of the larger reinforcer. Future research is necessary to address this

question. The results of Experiment 1 show that reinforcer magnitude is one environmental variable that can alter rates of delay discounting. These results are important because the identification of variables capable of altering delay discounting may have treatment implications in impulsive-control disorders.

Additionally, we found that the different baseline rates of delay discounting resulted in different effects of *d*-AMP on delay discounting. Specifically, *d*-AMP increased choice for the larger reinforcer in the SM Condition, and decreased choice for the larger reinforcer in the LM Condition. It seems that baseline rate of delay discounting is an important variable to consider when examining effects of *d*-AMP on delay discounting. Baseline rate does not, however, provide an explanation for the different effects observed. Rather, one potential reason for these different effects may have to do with the fact that *d*-AMP can affect both sensitivity to amount and delay, and may affect whichever parameter is higher to a greater degree. Furthermore, other variables, such as procedural variations, are likely responsible for some of the differences in effects of *d*-AMP observed. Future research is necessary in completely understanding effects of *d*-AMP on delay discounting. However, results from Experiment 2 highlight the importance of taking the environmental conditions into account when examining effects drugs on delay discounting. Overall, the results from the present study are important because they show that impulsive choice can be altered through environmental and pharmacological manipulations, and show that effects of *d*-AMP on impulsive choice are different when different environmental contexts are arranged. In the development of successful behavioral and pharmacological interventions for impulsive-choice disorders, it is critical to understand variables that control impulsive choice, and how context alters effects that are observed.

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