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# Delay and Probability Discounting in Cocaine Use Disorder: Comprehensive Examination of Money, Cocaine, and Health Outcomes Using Gains and Losses at Multiple Magnitudes

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Understanding factors associated with cocaine use disorder is important given its public health impact. One factor is delay discounting (devaluation of future consequences). Cocaine users have shown greater delay discounting of money rewards than non–cocaine users. But underexamined are factors known to affect discounting, such as the sign (reward vs. loss), magnitude (e.g., $10 vs. $1,000), and commodity (e.g., money vs. health) of the consequence. Also underexamined is probability discounting (devaluation of uncertain consequences). We conducted a comprehensive group-comparison study of discounting processes by comparing sign, magnitude, and commodity effects between demographically matched cocaine users ($n = 23$) and never users ($n = 24$) for delay discounting and sign and magnitude effects for probability discounting. Participants completed delay and probability discounting tasks spanning rewards and losses; money, cocaine, and health outcomes; and magnitudes of $10, $100, and $1,000. Four primary findings emerged when controlling for other drug use. First, cocaine users pervasively discounted delayed consequences more than never users regardless of sign, magnitude, or commodity, with the possible exception of delay discounting of $1,000 health equivalences. Second, both groups discounted delayed rewards more than losses, with a similar trend for probability discounting. Third, magnitude effects in cocaine users for delayed and probabilistic outcomes were similar to those previously observed in never users and other-drug users. Fourth, cocaine users discounted cocaine-related outcomes more than money and health, with variable results comparing money and health. These data suggest that the behavioral processes of delay and probability discounting are qualitatively similar for cocaine users and never users. However, quantitatively, cocaine users generally showed greater delay discounting and similar probability discounting compared with never users.

***Public Health Significance***
This is the most comprehensive within-subject comparison of discounting processes between cocaine users and never users, spanning rewards and losses; money, cocaine, and health outcomes; and magnitudes of $10, $100, and $1,000. This study suggests that discounting processes are qualitatively similar for cocaine users and never users, but cocaine users generally showed quantitatively greater delay discounting and similar probability discounting compared with never users.

*Keywords:* delay discounting, cocaine use disorder, sign effect, magnitude effect, amount effect



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Cocaine use is associated with many health complications resulting from acute toxicity and chronic use (e.g., cardiac, pulmonary, and hepatic toxicities and high risk of death; Riezzo et al., 2012). These many forms of negative consequences typically involve delay and/or uncertainty. Therefore, cocaine use has been studied through the lens of behavioral discounting processes.

Delay and probability discounting refer to observations that delayed or probabilistic (uncertain) outcomes have less value than immediate or certain outcomes, respectively. Researchers typically use choice procedures to determine the extent to which outcomes are devalued due to delay or probability, by pitting smaller immediate outcomes versus larger delayed outcomes or pitting smaller certain outcomes versus larger uncertain outcomes (e.g., Rachlin, Raineri, & Cross, 1991). For example, many people would take $90 right now over $100 in 1 year even though $100 is more than $90, indicating that the value of $100 is reduced as a function of the delay. Similarly, many people would prefer $90 for certain over a 50% chance at $100, indicating that the value of $100 is reduced by uncertainty. Delay and probability discounting are pervasive, likely occurring in all animal species (e.g., Addessi, Paglieri, & Focaroli, 2011; Budenberg, 2014; Dandy & Gatch, 2009; Green, Myerson, & Calvert, 2010; Mazur, 2006; Stevens, Hallinan, & Hauser, 2005; Stevens & Mühlhoff, 2012; Vanderveldt, Oliveira, & Green, 2016), and have many outcomes, including receiving or losing commodities (e.g., Calvert, Green, & Myerson, 2010; Kirby, Petry, & Bickel, 1999; Odum & Rainaud, 2003) and other experiences (e.g., Johnson & Bruner, 2012; Lawyer, 2008). Despite this pervasiveness, the extent of discounting (i.e., the degree to which delay or uncertainty devalues an outcome) can vary strongly between individuals and situations.

## Group-Comparison Studies

One form of evidence linking cocaine use to discounting has been comparisons between cocaine users and controls. Group-comparison studies have broadly found cocaine use to be associated with increased delay discounting. For example, compared with control groups, cocaine users show greater delay discounting of monetary rewards (e.g., Coffey, Gudleski, Saladin, & Brady, 2003; Heil, Johnson, Higgins, & Bickel, 2006; Johnson, 2012; Kirby & Petry, 2004), preferred liquids (Mejía-Cruz, Green, Myerson, Morales-Chainé, & Nieto, 2016), and condom-protected sex for a subset of potential sexual partners (Johnson, Johnson, Herrmann, & Sweeney, 2015).

There are a few caveats to the broad group-based associations between cocaine use and discounting. For delay discounting, cocaine users and nonusers have not significantly differed in discounting delayed monetary losses or leisure activities (Mejía-Cruz et al., 2016). For probability discounting, cocaine users and nonusers have not shown significant differences in discounting of monetary rewards (Johnson, Johnson, et al., 2015; Mejía-Cruz et al., 2016), monetary losses (Mejía-Cruz et al., 2016), sexual outcomes (Johnson, Johnson, et al., 2015), leisure activities (Mejía-Cruz et al., 2016), or preferred liquid rewards (Mejía-Cruz et al., 2016).

Aside from cocaine, studies have found greater monetary delay discounting in several drug-using groups compared with controls. This suggests the possibility that a common predisposition toward frequent drug use or addiction accounts for group differences rather than, or in addition to, the pharmacological effects of cocaine. This effect has been found for alcohol (MacKillop et al., 2010; Vuchinich & Simpson, 1998), methamphetamine (Hoffman et al., 2006), tobacco (e.g., Baker, Johnson, & Bickel, 2003; Bickel, Odum, & Madden, 1999; Johnson, Bickel, & Baker, 2007; Mitchell, 1999), and opioids (e.g., Kirby et al., 1999; Madden, Petry, Badger, & Bickel, 1997), although cannabis may constitute an exception (Johnson et al., 2010; Strickland, Lile, & Stoops, 2017). Similar to cocaine use, monetary probability discounting does not consistently differ between smokers and nonsmokers (e.g., Białaszek, Marcowski, & Cox, 2017; Mitchell, 1999; Ohmura, Takahashi, & Kitamura, 2005; but in contrast, see Reynolds, Richards, Horn, & Karraker, 2004; Yi, Chase, & Bickel, 2007) or between marijuana-dependent and nondependent users (Mejía-Cruz et al., 2016).

## Cocaine Administration Studies

Administering cocaine to cocaine users caused no significant change in delay or probability discounting of money (Johnson, Herrmann, Sweeney, LeComte, & Johnson, 2017). However, the same study found that cocaine administration increased delay discounting of condom-protected sex and increased probability discounting of sexual outcomes (i.e., the effect of sexually transmitted infection uncertainty on decreasing the likelihood of condom use) in a dose-dependent manner (Johnson et al., 2017). Interestingly, cocaine users continue to steeply discount monetary rewards at 14 (Kirby & Petry, 2004) and 30 days (Heil et al., 2006) after cocaine cessation. This suggests either persistent effects of cocaine use on delay discounting or that a common predisposition, rather than a causal effect of cocaine, accounts for elevated monetary delay discounting among cocaine users.

Persistent preference for smaller-sooner over larger-later rewards has also been observed after chronic cocaine exposure in rats (e.g., Koffarnus & Woods, 2013; Logue et al., 1992; Roesch, Takahashi, Gugsa, Bissonette, & Schoenbaum, 2007; Setlow, Mendez, Mitchell, & Simon, 2009). Additionally, the persistent effects of cocaine on delay discounting have been found to last for 3 months after cocaine cessation (Mendez et al., 2010; Simon, Mendez, & Setlow, 2007), and rats that self-administered cocaine at higher rates showed the greatest discounting changes from baseline (Dandy & Gatch, 2009; Mitchell et al., 2014). No significant effect of cocaine on probability discounting has been observed with rats (Mendez et al., 2010).

## Outcome Specificity and Discounting

Robust evidence indicates that the extent of discounting will change for most people depending on the specific details of the choice. For example, Baker and colleagues (2003) comprehensively examined delay discounting in current and never smokers across gains and losses of money, health, and cigarettes (smokers only) and at outcome amounts of $10, $100, and $1,000. They observed pervasively steeper delay discounting in smokers compared with nonsmokers, but they also found that discounting was steeper for gains compared with losses, for smaller amounts compared with larger amounts, and for cigarettes compared with money (Baker et al., 2003). These results were subsequently replicated with light smokers (10 or fewer cigarettes per day; Johnson et al., 2007), who did not differ significantly from the heavy smokers in the Baker et al. (2003) study. Intriguingly, all three groups did not differ significantly in the extent to which they discounted health outcomes, and both smoking groups (light vs. heavy) discounted cigarettes similarly.

In some cases, aberrant discounting has been observed only with outcomes related to the problem behavior. Shallower probability discounting has been observed for food in people with an elevated body-fat percentage, but no differences have been observed for probability discounting of money (e.g., Rasmussen, Lawyer, & Reilly, 2010; but in contrast, also see Hendrickson & Rasmussen, 2013). Administration of cocaine and alcohol, two drugs that are associated with risky sexual behavior, caused increases in delay and probability discounting of sexual consequences, as previously mentioned, but had no significant effect or minimal effects on delay and probability discounting of money (Johnson et al., 2017; Johnson, Sweeney, Herrmann, & Johnson, 2016). Although only money was studied, several studies indicate that problem gamblers aberrantly discount money, the outcome typically at play with gambling. Compared with control groups, greater delay discounting of monetary rewards has been observed with pathological gamblers (e.g., Madden, Francisco, Brewer, & Stein, 2011), and shallower probability discounting has been observed for monetary outcomes in gamblers (e.g., Holt, Green, & Myerson, 2003; Madden, Petry, & Johnson, 2009; Shead, Callan, & Hodgins, 2008). Together, these data suggest that delay and probability discounting are not monolithic constructs and that relations and effects often depend on a number of factors, including the sign, magnitude, and commodity of the discounted outcome.

## Sign Effect

The sign effect describes the observation that both delayed and uncertain gains (or rewards) are discounted more than losses (or punishments; e.g., Kahneman & Tversky, 1979, 1984; Thaler, 1981; Thaler, Tversky, Kahneman, & Schwartz, 1997). For example, a $100 reward delayed by a year might be subjectively equivalent to $60 now (a 40% reduction). But for the same person, a $100 loss delayed by a year might be subjectively equivalent to an $80 loss now (only a 20% reduction). Similarly, a 50% chance at a $100 reward might be subjectively equivalent to a certain $60 reward (40% reduction). But for the same person, a 50% chance at a $100 loss might be subjectively equivalent to a certain $80 loss (20% reduction). The sign effect has been found to occur with delayed monetary outcomes (e.g., Estle, Green, Myerson, & Holt, 2006; Murphy, Vuchinich, & Simpson, 2001; Thaler, 1981), probabilistic monetary outcomes (e.g., Estle et al., 2006; Shead & Hodgins, 2009), delayed health outcomes (e.g., Baker et al., 2003; Chapman, 1996), delayed cigarettes (Baker et al., 2003), and delayed cocaine (Johnson, Bruner, & Johnson, 2015).

## Magnitude (Amount) Effect

The magnitude effect describes the observation that smaller amounts (e.g., $10) are discounted to a different extent than larger amounts (e.g., $1,000), with the direction differing between delay and probability discounting. For delayed rewards, small amounts are discounted more than large amounts (e.g., Green, Myerson, & McFadden, 1997; Kirby, 1997; Thaler, 1981). For example, a $100 reward delayed by a year might be subjectively equivalent to a $60 reward now (a 40% reduction). But for the same person, a $1,000 reward delayed by a year might be subjectively equivalent to an $800 reward now (only a 20% reduction). A magnitude effect for delayed rewards has been found to occur with real money (e.g., Johnson & Bickel, 2002), hypothetical money (e.g., Green et al., 1997), hypothetical health (e.g., Chapman, 1996; Chapman & Elstein, 1995), and even hypothetical vacations and rental cars (Raineri & Rachlin, 1993). For probabilistic rewards, the opposite occurs; small amounts are discounted less than large amounts (e.g., Myerson, Green, & Morris, 2011). The opposite effect that changing magnitude has on discounting delayed and probabilistic outcomes is the strongest evidence that delay and probability discounting are fundamentally different processes. Shallower probability discounting of larger amounts has been found to occur with hypothetical money (e.g., Estle et al., 2006; Myerson et al., 2011) and points in a computer game (e.g., Greenhow, Hunt, Macaskill, & Harper, 2015). Lastly, a magnitude effect is typically not observed for delayed or uncertain losses (e.g., Green, Myerson, Oliveira, & Chang, 2014; Miranda, Drabek, & Cox, 2018; but in contrast, also see Cox & Dallery, 2016).

## Domain/Commodity Effect

The commodity effect occurs when the extent of discounting differs depending on the commodity under consideration (e.g., Chapman & Elstein, 1995; Madden et al., 1997; Madden, Bickel, & Jacobs, 1999). Generally, delayed and probabilistic consumable commodities and events (e.g., alcohol, cigarettes, cocaine, food, heroin) are discounted more steeply than money (e.g., delay: Baker et al., 2003; Bickel et al., 1999; Coffey et al., 2003; Madden et al., 1997, 1999; probability: Rasmussen et al., 2010). Steeper discounting appears to result from the consumable nature of tangible outcomes, rather than anything particular about drug reinforcers, because food is also discounted more than money (Estle, Green, Myerson, & Holt, 2007; Odum & Rainaud, 2003). Interestingly, mixed results exist for less tangible commodities (health outcomes), which have been found to be discounted less than money (e.g., Baker et al., 2003; Friedel, DeHart, Frye, Rung, & Odum, 2016) and more than money (Chapman, 1996; Chapman & Elstein, 1995). Other relevant outcomes for cocaine users are access to cocaine and health outcomes, which have not been comparatively examined.

## Comprehensive Comparison of Discounting

Outcome specificity has emerged as a general theme in the discounting literature. That is, the extent of discounting may differ depending on the sign, magnitude, and commodity of the outcomes being considered. Several of these outcome characteristics have been compared in cocaine users (e.g., sign effect [Johnson, Bruner, & Johnson, 2015]; magnitude effect [Kirby & Petry, 2004]) or between cocaine users and never users (e.g., delay and probability discounting of multiple commodities [Johnson, Johnson, et al., 2015]). However, we are not aware of any research that has comprehensively examined both delay and probability discounting across multiple signs, magnitudes, and commodities in demographically matched cocaine users and never users. This was the purpose of the current study.

To comprehensively examine discounting in cocaine users and never users, we analyzed unpublished data that were collected from participants in a previously published study (Johnson, Johnson, et al., 2015) in conjunction with the data on $100 monetary gain delay discounting and $100 monetary gain probability discounting published in that same study (Johnson, Johnson, et al., 2015). The previous publication by Johnson, Johnson, et al. (2015) was focused on the differences between cocaine users and never users in discounting of sexual outcomes. The $100 monetary delay and probability gain tasks were included as comparators to determine if any differences were specific to sexual outcomes. For the present analysis, we were interested in broadly examining discounting characteristics that were not directly relevant to the previous analysis. Specifically, we compared sign, magnitude, and domain/commodity effects between cocaine users and never users for delay discounting and sign and magnitude effects for probability discounting. The present study constitutes the most robust examination of discounting processes in human cocaine users to date.

# Method

## Participants

Participants were cocaine-using ($n = 23$) or never-using ($n = 24$) individuals recruited from the Baltimore area using flyers and Internet, newspaper, and radio advertisements. All participants were 18 years of age or older and had an eighth-grade reading level or higher. Participants in the cocaine group also met *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM–IV*; American Psychiatric Association, 1994) criteria for cocaine abuse or dependence. Control participants reported no lifetime use of cocaine. Participants in both groups could meet the criteria for abuse of drugs other than cocaine but could not meet the dependence criteria for drugs other than nicotine and caffeine. Exclusion criteria for both groups were self-reported head trauma, dementia, significant cognitive impairment, or a diagnosis of major psychiatric disorder other than substance abuse/dependence.

## Procedure

Following a telephone screen, potentially qualified participants came to a laboratory for an in-person screen. During the in-person screen, participants completed an informed consent, a demographic questionnaire, a lifetime drug use questionnaire, and an assessment of current and past drug abuse and dependence and gave a urine sample to test for recent presence of cocaine, amphetamine, methamphetamine, morphine, and cannabinoids. Participants also completed two standardized assessments for matching purposes. These were the Quick Test for verbal intelligence (Ammons & Ammons, 1962) and the Wide Range Achievement Test for reading comprehension (Wilkinson, 1993). Participants completed the discounting tasks after completing the intake process.

**Monetary delay discounting.** We assessed monetary delay discounting using a computerized task published previously (e.g., Johnson, 2012; Johnson, Bickel, & Baker, 2007; Johnson & Bickel, 2002; Johnson, Bruner, et al., 2015). All outcomes were hypothetical. On each trial, participants chose between an immediate, small amount of money and a delayed, large amount of money for one of three larger delayed reward magnitudes ($10, $100, and $1,000). For each trial, participants were asked to treat the outcomes as real and to consider their current finances. A computer algorithm adjusted the magnitude of the smaller, immediate option across trials for each larger, delayed magnitude reward (see Richards, Zhang, Mitchell, & de Wit, 1999 for a description of the algorithm). The algorithm resulted in an indifference point for each participant at each of seven delays: 1 day, 1 week, 1 month, 6 months, 1 year, 5 years, and 25 years. The order in which delays were assessed (ascending or descending) was counterbalanced across participants. Each participant completed six monetary delay discounting tasks—one each for gaining the previously noted amounts and one each for losing the previously noted amounts. For each loss trial, participants chose between losing an immediate, smaller amount of money and a delayed, larger amount of money. For money and all other loss conditions, the algorithm differed from gains such that choosing the smaller outcome increased the value of the smaller outcome across trials (rather than decreased as in the gains conditions), and choosing the larger outcome decreased the value of the smaller outcome across trials (Baker et al., 2003).

**Monetary probability discounting.** We assessed monetary probability discounting using a previously published task analogous to the previously described monetary delay discounting task (Yi, Johnson, & Bickel, 2005). All outcomes were hypothetical. Participants chose between a small, certain amount of money and a large, uncertain amount of money across three magnitudes ($10, $100, or $1,000). Participants were asked to treat the outcomes as real and to consider their real-life finances. Each participant's pattern of responding led to an indifference point at each of seven probabilities: 99%, 90%, 75%, 50%, 25%, 10%, and 1%. The order in which probability values were assessed for each participant (ascending or descending) matched what the participant experienced in the delay discounting task. All participants completed six probability discounting tasks—one each for gaining the previously noted amounts and one each for losing the previously noted amounts.

**Delay discounting health outcomes.** To assess discounting of health outcomes, participants first provided an estimate of health value (see Baker et al., 2003 for full description). Briefly, participants estimated a duration of 10% improved health that was subjectively equivalent to getting $100 immediately. The duration provided was then used as the larger amount in the health gains of $100 discounting task. For example, a participant might state that 3 months of 10% better health was equivalent to getting $100 immediately. A trial of delay discounting health gains would have them choose between a shorter duration of improved health now and 3 months of 10% better health after a delay. The shorter-immediate duration would adjust based on each choice using the same computer algorithm as described previously. Indifference points were obtained at the same seven delays used in the monetary delay discounting tasks. The process of estimating health values for use in the health discounting tasks was repeated for health gains equivalent to $1,000, health losses equivalent to $100, and health losses equivalent to $1,000. For losses, the word *improved* was replaced by *worse*.

**Delay discounting cocaine-related outcomes.** Participants completed two delay discounting tasks of cocaine gains (amounts of $100 and $1,000). Participants first indicated whether they typically consume cocaine in powdered or rock (crack) form. Their stated preference was then used in the delay discounting cocaine gains and losses tasks. The choice options in cocaine-related tasks were framed as nickel quantities ($5 worth) of cocaine sold in the Baltimore area. The delay discounting tasks asked participants to choose between a smaller quantity of nickel rocks/vials of powder immediately and 20 ($100 worth of cocaine) or 200 ($1,000 worth of cocaine) after a delay. The delays and adjusting algorithm used were similar to those in the discounting tasks described previously.

Participants also completed two delay discounting tasks of cocaine-related losses in a manner similar to that for health discounting. Each participant estimated two durations of cocaine abstinence that were subjectively equivalent to losing $100 and losing $1,000 immediately. Estimated durations were used in delay discounting tasks where participants chose between a shorter duration of cocaine abstinence starting immediately or a longer duration of abstinence starting after a delay. The calculation of indifferences points and the delays used were identical to those described for the discounting tasks.

All participants completed the discounting tasks in the following order: money delay discounting gains, money delay discounting losses, health delay gains, health delay losses, money probability discounting gains, money probability discounting losses, cocaine delay discounting gains (cocaine participants only), and cocaine delay discounting losses (cocaine participants only). The order of magnitudes that each participant experienced was randomly set to either ascending ($10, $100, $1,000) or descending ($1,000, $100, $10). However, each participant completed the same order across all tasks.

Study procedures were approved by the Johns Hopkins Medicine Institutional Review Board 3 (Office for Human Research Protections Registration 00001656). The study was conducted in accord with the principles expressed in the Declaration of Helsinki, and written informed consent was obtained from all participants. The collection of these data was part of a larger study (see Johnson, Johnson, et al., 2015), and participants received $250 in total compensation for their participation.

## Data Analysis

Data were examined for orderliness using previously published criteria for nonsystematic patterns of responding (Johnson & Bickel, 2008; Johnson, Herrmann, & Johnson, 2015). The first criterion was whether, beginning with the second indifference point, the indifference point exceeded the preceding indifference point by more than 20% of the larger outcome (e.g., more than $200 if the larger-later outcome was $1,000; Johnson & Bickel, 2008). The second criterion was that the final indifference point could not exceed the first indifference point by more than 10% (e.g., more than $100 if the larger-later outcome was $1,000; Johnson, Herrmann, et al., 2015). These criteria were used to characterize the data rather than to identify data for elimination. All data were retained for subsequent analyses.

The shape of a delay discounting curve is often well described by a hyperbolic equation (Mazur, 1987), written as follows:

$$I = \frac{1}{1 + kD}. \quad (1)$$

Here, $I$ is the indifference point, expressed as a proportion of the delayed reward amount; $D$ is the delay to receiving the reward; and $k$ is a discounting parameter that estimates the extent of discounting. Probability discounting uses the same equation, with the exception of odds against (calculated as $[1 - p]/p$, where $p$ is probability) instead of delay and with the letter $h$ used to represent the extent of probability discounting. Greater preference for immediate/certain alternatives is represented by higher $k/h$ values. Greater preference for delayed/uncertain alternatives is represented by lower $k/h$ values.

Nonlinear regression was used to fit Equation 1 to the seven indifference points for each participant and for each outcome condition (i.e., for a single magnitude of delayed/uncertain reward and for a single valence [gain or loss]). This resulted in a best-fit estimate of the discounting parameter $k$ for delay tasks and $h$ for probability tasks. We did not remove any participants from the data analysis, given the comprehensive nature of the comparisons being made. All parametric statistical tests were performed on the natural log transform of $k/h$ because the raw distribution of estimated $k$ and $h$ values were positively skewed (average Pearson's coefficient of skewness = 1.06 for $k$ and 0.86 for $h$).

A planned series of five analyses of variance (ANOVA) was conducted (see Table 1). ANOVA 1 focused on delay discounting of money, where cocaine status was the between-subjects variable (cocaine user or nonuser), sign was the first within-subject variable (gain or loss), and money amount was the second within-subject variable ($10, $100, or $1,000). ANOVA 2 was identical to ANOVA 1, with the exception that it analyzed probability, rather than delay, discounting. ANOVA 3 focused on delay discounting of health, where cocaine status was the between-subjects variable, sign was the first within-subject variable, and health amount was the second within-subject variable ($100 or $1,000 equivalencies). ANOVA 4 focused on the sign, magnitude, and commodity effects for delay discounting, where cocaine status was the between-subjects variable, sign was the first within-subject variable, outcome amount was the second within-subject variable (only $100 or $1,000 equivalencies), and commodity was the third within-subject variable (money or health). Finally, ANOVA 5 focused on cocaine users only, examining the sign (gain or loss), magnitude ($100 or $1,000 equivalencies), and commodity effects (money, health, or cocaine). Any significant interaction in the ANOVAs was followed up by simple effect analyses (ANOVAs or $t$ tests) exploring the nature of the interaction. We used Greenhouse–Geiser corrections wherever Mauchly's test of sphericity was significant, indicating unequal variance across within-subject conditions (denoted by noninteger degrees of freedom).

# Results

## Demographic Characteristics

Demographic descriptions of the cocaine group ($n$ = 23) and healthy controls ($n$ = 24), which were previously published (Johnson, Johnson, et al., 2015), are presented in Table 2. Groups did not significantly differ across age, race, sex, marital status, income, education, or intelligence. Participants did not differ in cigarette or opiate use in the year prior to the study, but individuals in the cocaine group reported greater consumption of alcohol and cannabis relative to the healthy controls. The number of participants

Table 1
*Summary of Planned ANOVAs*

| ANOVA number | Focus | Between-subjects variable | Within-subject variable 1 | Within-subject variable 2 | Within-subject variable 3 |
|---|---|---|---|---|---|
| 1 | Delay discounting money | Cocaine status (user or nonuser) | Sign (gain or loss) | Money amounts ($10, $100, $1,000) | — |
| 2 | Probability discounting money | Cocaine status (user or nonuser) | Sign (gain or loss) | Money amounts ($10, $100, $1,000) | — |
| 3 | Delay discounting health | Cocaine status (user or nonuser) | Sign (gain or loss) | Health amounts ($100, $1,000) | — |
| 4 | Delay discounting all effects | Cocaine status (user or nonuser) | Sign (gain or loss) | Amounts ($100, $1,000) | Commodities (money or health) |
| 5 | Cocaine users all effects | — | Sign (gain or loss) | Amounts ($100, $1,000) | Commodities (money, health, cocaine) |

*Note.* ANOVA = analysis of variance.

who tested positive for cocaine, amphetamine, methamphetamine, morphine, and cannabinoids in the cocaine group was 14, 0, 0, 1, and 7, respectively. In the control group, three participants were positive for cannabinoids, but no participants were positive for any other drugs.

All participants in the cocaine group met *DSM–IV* criteria for cocaine abuse, and 20 (87%) met the criteria for cocaine dependence. Self-reported preferred cocaine administration methods were inhalation (smoking crack) for 18 participants (78%), intranasal for 4 participants (17%), and intravenous for 1 participant (4%).

## Data Orderliness

Participants completed the discounting tasks in a mean (standard deviation [*SD*]) of 98 (43) trials, which equates to a mean (*SD*) of approximately 14 (6) trials per indifference point. Appendix A provides the box-and-whisker distribution values for each of the total trials required per discounting task. Table 3 shows the number of participants from each group who met the criteria for nonsystematic patterns of responding (Johnson & Bickel, 2008; Johnson, Herrmann, et al., 2015). For the criteria, in all conditions, the majority of data sets did not violate the criteria. Data were generally more orderly for money compared with other commodities and for gains compared with losses. The median (mean) number of indifference points that violated Criterion 1 was 1.00 (1.14) and 1.00 (1.11) for the cocaine and control groups, respectively.

## Discounting Tasks

Figure 1 shows the median, untransformed discount rates for participants in the cocaine and control groups across discounting tasks of varying sign, magnitude, commodity, and process (delay and probability). Table 4 shows the results of ANOVA 1, focused on delay money discounting (corresponding to Panel A, Figure 1). We observed a main effect of cocaine use status; cocaine users discounted more than never users. We also observed main effects for sign and magnitude, with gains being discounting more than losses overall and smaller amounts being discounted more than larger amounts overall, but there was an interaction between sign and magnitude. Follow-up analyses showed that small gains were discounted more than large gains (i.e., statistically significant simple effect of magnitude for gains; $F[1.68, 75.72] = 14.92$, $p < .001$, $\eta_p^2 = 0.249$), but magnitude did not influence discounting for losses (i.e., no statistically significant simple effect of magnitude for losses; $F[1.76, 79.03] = 0.98$, $p = .88$, $\eta_p^2 = 0.002$). Also, gains were discounted more than losses at $10 ($t_{91} = 3.00$, $p = .004$) and $100 ($t_{91} = 1.95$, $p = .05$) but not at $1,000 ($t_{91} = 1.58$, $p = .12$). Appendix B shows the results of the same ANOVA when controlling for alcohol and cannabis use as covariates.

Table 5 shows the results of ANOVA 2, focused on probability money discounting (corresponding to Panel B, Figure 1). We observed a main effect of magnitude; larger amounts were generally discounted more than smaller amounts (magnitude effect). We did not observe a main effect of cocaine use status or sign on probability discounting of money, but a nonsignificant trend was present that suggested greater discounting of gains than losses (sign effect). However, we also observed Group × Magnitude and Sign × Magnitude interactions. Follow-up analyses for the

Table 2
*Sample Demographic and Substance Use Characteristics*

| Characteristic | Cocaine ($n$ = 23) | Control ($n$ = 24) | Test statistic | $p$-value |
|---|---|---|---|---|
| Demographics | | | | |
| Age in years, mean (*SD*) | 46.3 (10.9) | 40.0 (15.3) | $t_{(45)} = 1.62$ | .11 |
| Sex, count (%) | | | | |
| Male | 13 (57) | 15 (63) | | .77 |
| Female | 10 (43) | 9 (38) | | |
| Race, count (%)[a,b] | | | | .76 |
| African American/Black | 14 (61) | 17 (71) | | |
| Caucasian/White | 8 (35) | 7 (29) | | |
| More than one race | 1 (4) | 0 (0) | | |
| Marital status, count (%) | | | | 1.00 |
| Nonmarried (single/separated/divorced/widowed) | 20 (87) | 21 (88) | | |
| Married | 3 (13) | 3 (13) | | |
| Education in years, mean (*SD*) | 13.1 (1.7) | 13.8 (1.6) | $t_{(45)} = 1.49$ | .14 |
| Monthly income in U.S. dollars, mean (*SD*) | 1,186 (826) | 1,369 (1,222) | $t_{(45)} = .59$ | .55 |
| Quick Test intelligence score, mean (*SD*) | 43.2 (3.4) | 41.6 (4.1) | $t_{(45)} = 1.44$ | .16 |
| Substance Use | | | | |
| Cocaine | | | | |
| Number reporting use in past year (%) | 23 (100) | — | | |
| Frequency of use (days per month), mean (*SD*) | 16.0 (9.1) | — | | |
| Number meeting *DSM–IV* criteria for current abuse (%) | 23 (100) | — | | |
| Number meeting *DSM–IV* criteria for current dependence (%) | 20 (87) | — | | |
| Alcohol | | | | |
| Number reporting use in past year (%) | 22 (96) | 17 (71) | | .048 |
| Frequency of use (days per month), mean (*SD*) | 10.2 (10.4) | 1.5 (3.3) | $t_{(45)} = 3.90$ | <.0001 |
| Number meeting *DSM–IV* criteria for current abuse (%) | 7 (30) | 1 (4) | | .02 |
| Cannabis | | | | |
| Number reporting use in past year (%) | 16 (70) | 6 (25) | | <.01 |
| Frequency of use (days per month), mean (*SD*) | 5.2 (9.9) | 2.0 (7.0) | $t_{(45)} = 1.30$ | .20 |
| Number meeting *DSM–IV* criteria for current abuse (%) | 5 (22) | 0 (0) | | .02 |
| Opiates | | | | |
| Number reporting use in past year (%) | 6 (26) | 2 (8) | | .14 |
| Frequency of use (days per month), mean (*SD*) | 1.0 (3.2) | .007 (.02) | $t_{(45)} = 1.53$ | .13 |
| Number meeting *DSM–IV* criteria for current abuse (%) | 1 (4) | 0 (0) | | .49 |
| Cigarettes smoked per day, mean (*SD*) | 6.9 (5.4) | 4.3 (7.6) | $t_{(45)} = 1.39$ | .17 |

*Note*. *DSM–IV* = *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.).
[a] All participants identified as non-Hispanic. [b] Race categorized as White/Caucasian versus Other.

Group × Magnitude interaction found that cocaine users discounted \$1,000 more than \$10 ($t_{45}$ = 2.63, $p$ = .012) and \$1,000 more than \$100 ($t_{45}$ = 3.23, $p$ = .002), but there were no differences between cocaine users' discounting of \$10 and \$100 ($t_{45}$ = 0.03, $p$ = .98) nor for any magnitude comparisons within the control group (all $p \geq .19$). Additionally, there were no differences in probability discounting between cocaine users and the control group at any magnitude (all $p \geq .37$). Follow-up analyses for the Magnitude × Sign interaction found that \$1,000 gains were discounted more steeply than \$10 gains ($t_{46}$ = 2.36, $p$ = .023) and \$100 gains ($t_{46}$ = 2.95, $p$ = .005); \$100 gains were discounted more than \$100 losses ($t_{46}$ = 2.31, $p$ = .025); and \$1,000 gains were discounted more than \$1,000 losses ($t_{46}$ = 2.95, $p$ = .005). All other pairwise comparisons for the Magnitude × Sign interaction were not significant ($p > .08$).

Table 6 shows the results of ANOVA 3 for delay health discounting (corresponding to Panel C, Figure 1). We observed main effects for outcome sign and outcome magnitude. Health-related gains were discounted more than losses, and smaller health-related outcomes were discounted more than larger health-related outcomes. We did not observe a main effect of cocaine use status, although a nonsignificant trend was present that suggested greater discounting in the cocaine group.

Table 7 shows the results of ANOVA 4 for delay discounting across money and health at \$100 and \$1,000 equivalencies for both groups. We observed significant main effects showing greater delay discounting for cocaine users compared with never users, gains compared with losses (sign effect), and small amounts compared with large amounts (magnitude effect). We found no statistically significant difference between discounting money compared with discounting health (no commodity effect). But we did observe Sign × Commodity and Magnitude × Commodity interactions. Follow-up analyses for the Sign × Commodity interaction showed that money losses were discounted more than health losses, $F(1, 44) = 4.61$, $p = .037$, $\eta_p^2 = 0.093$, and there was no difference between discounting health gains and money gains, $F(1, 44) = 0.77$, $p = .385$, $\eta_p^2 = 0.017$. Gains were discounted more than losses for health, $F(1, 44) = 12.20$, $p < .001$, $\eta_p^2 = 0.217$, but no difference was found in discounting gains or losses for money, $F(1, 44) = 2.88$, $p = .097$, $\eta_p^2 = 0.060$. Follow-up analyses for the Magnitude × Commodity interaction showed that health-related \$100 equivalence was discounted more than health-related \$1,000 equivalence, $F(1, 44) = 13.85$, $p < .001$, $\eta_p^2 = 0.239$, but there was no difference between \$100 money and \$1,000 money, $F(1, 44) = 2.22$, $p = .143$, $\eta_p^2 = 0.047$. Also, money was discounted similarly to health-related equivalence at both \$1,000, $F(1, 44) =$

Table 3
*Number (Percentage) of Participants Meeting Orderliness Criteria*

| Task | Cocaine group ($n$ = 23) | | Control group ($n$ = 24) | |
|---|---|---|---|---|
| | Criterion 1 | Criterion 2 | Criterion 1 | Criterion 2 |
| $10 delayed monetary gain | 1 (4%) | 0 (0%) | 1 (4%) | 0 (0%) |
| $100 delayed monetary gain | 1 (4%) | 0 (0%) | 1 (4%) | 0 (0%) |
| $1,000 delayed monetary gain | 1 (4%) | 0 (0%) | 2 (9%) | 0 (0%) |
| $10 delayed monetary loss | 4 (17%) | 0 (0%) | 1 (4%) | 0 (0%) |
| $100 delayed monetary loss | 5 (22%) | 0 (0%) | 4 (17%) | 1 (4%) |
| $1,000 delayed monetary loss | 3 (13%) | 0 (0%) | 5 (22%) | 2 (8%) |
| $100 delayed health gain | 3 (13%) | 0 (0%) | 5 (22%) | 0 (0%) |
| $1,000 delayed health gain | 4 (17%) | 0 (0%) | 1 (4%) | 0 (0%) |
| $100 delayed health loss | 2 (9%) | 0 (0%) | 5 (22%) | 0 (0%) |
| $1,000 delayed health loss | 2 (9%) | 0 (0%) | 8 (35%) | 1 (4%) |
| $100 delayed cocaine gain | 2 (9%) | 0 (0%) | — | — |
| $1,000 delayed cocaine gain | 3 (13%) | 0 (0%) | — | — |
| $100 delayed cocaine loss | 10 (48%) | 2 (9%) | — | — |
| $1,000 delayed cocaine loss | 10 (48%) | 4 (17%) | — | — |
| $10 probability monetary gain | 0 (0%) | 0 (0%) | 3 (13%) | 0 (0%) |
| $100 probability monetary gain | 0 (0%) | 0 (0%) | 1 (4%) | 0 (0%) |
| $1,000 probability monetary gain | 2 (9%) | 0 (0%) | 2 (9%) | 0 (0%) |
| $10 probability monetary loss | 3 (13%) | 0 (0%) | 4 (17%) | 2 (8%) |
| $100 probability monetary loss | 5 (22%) | 1 (4%) | 2 (9%) | 1 (4%) |
| $1,000 probability monetary loss | 5 (22%) | 1 (4%) | 1 (4%) | 0 (0%) |

3.16, $p$ = .082, $\eta_p^2 = 0.066$, and $100, $F(1, 44) = 0.03$, $p$ = .854, $\eta_p^2 = 0.001$.

Finally, Table 8 shows the results of ANOVA 5, comparing delay discounting across sign; magnitude ($100 or $1,000); and the commodities of money-, health-, and cocaine-related outcomes in cocaine users only (corresponding to Panel D, Figure 1). We observed a main effect of commodity. Follow-up analyses found that cocaine-related outcomes were discounted more than health-

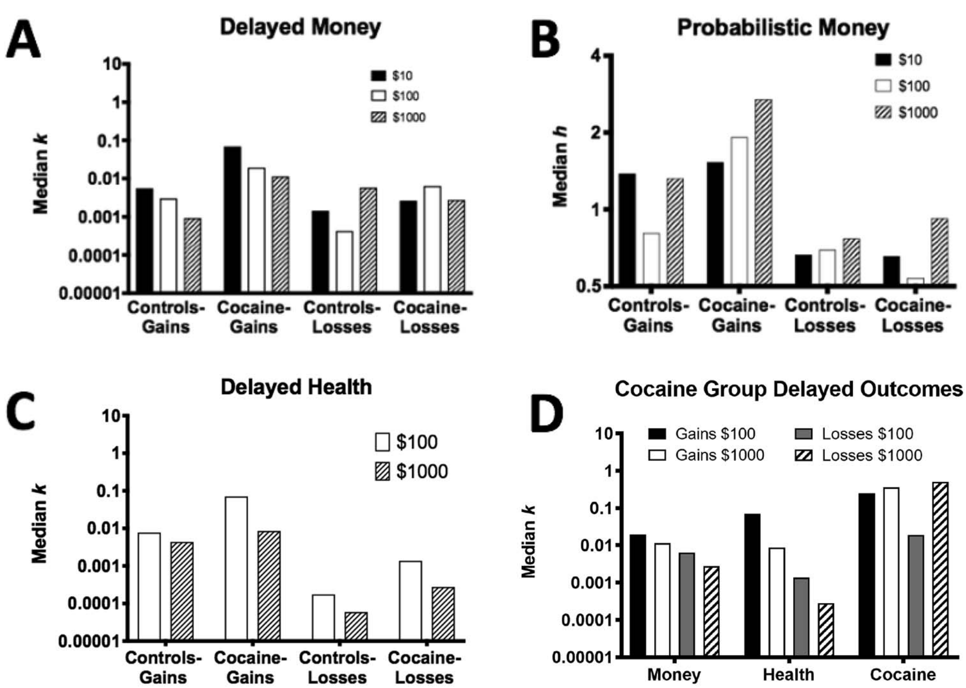


*Figure 1.* Median (untransformed) discount rates for delay discounting of hypothetical money (Panel A), probabilistic money (Panel B), and delayed health outcomes (Panel C) using a logarithmic y-axis. Panel D juxtaposes delay discounting of money, health- and cocaine-related outcomes in the cocaine group for easy comparison of discounting across different signs, magnitudes, and commodities.

Table 4
*Results of ANOVA 1 for Delay Money Discounting*

| Effect | *df*s | *F* | *p* | $\eta_p^2$ |
|---|---|---|---|---|
| Cocaine use (A) | 1,45 | 7.928 | .007* | .15 |
| Sign (B) | 1,45 | 4.988 | .031* | .10 |
| Magnitude (C) | 2,90 | 3.202 | .045* | .07 |
| A × B | 1,45 | .035 | .853 | .00 |
| A × C | 2,90 | .498 | .609* | .01 |
| B × C | 2,90 | 3.529 | .033 | .07 |
| A × B × C | 2,90 | .318 | .729 | .01 |

*Note.* ANOVA = analysis of variance.
* $p < .05$.

Table 6
*Results of ANOVA 3 for Delay Health Discounting*

| Effect | *df*s | *F* | *p* | $\eta_p^2$ |
|---|---|---|---|---|
| Cocaine use (A) | 1,44 | 3.283 | .077 | .07 |
| Sign (B) | 1,44 | 12.203 | .001* | .22 |
| Magnitude (C) | 1,44 | 13.846 | .001* | .24 |
| A × B | 1,44 | .199 | .658 | .01 |
| A × C | 1,44 | .008 | .927 | .00 |
| B × C | 1,44 | .078 | .781 | .00 |
| A × B × C | 1,44 | 1.156 | .288 | .03 |

*Note.* ANOVA = analysis of variance.
* $p < .05$.



related outcomes, $F(1, 21) = 21.89$, $p < .001$, $\eta_p^2 = 0.510$, and money outcomes, $F(1, 21) = 16.47$, $p < .001$, $\eta_p^2 = 0.440$, but there was no difference between discounting money and health-related outcomes, $F(1, 21) = 1.94$, $p = .177$, $\eta_p^2 = 0.081$. We also observed a nonsignificant trend in the main effect of sign for gains to be discounted more than losses, and there was no main effect for magnitude. However, there was a significant Magnitude × Commodity interaction. Follow-up analyses showed that at $1,000 equivalences, cocaine-related outcomes were discounted more than money ($t_{44} = 3.44$, $p = .001$), and cocaine-related outcomes were discounted more than health-related outcomes ($t_{44} = 4.32$, $p < .001$). Follow-up analyses also showed that at $100 equivalences, cocaine-related outcomes were discounted more than health-related outcomes ($t_{44} = 2.04$, $p = .047$). All remaining pairwise comparisons within magnitudes, but across commodities, were not significantly different (all *p*s ≥ .10). Finally, follow-up analyses showed that the only within-commodity, but across-magnitude, difference was greater discounting of $100 health-related outcomes than $1,000 health-related outcomes ($t_{44} = 3.12$, $p = .003$). All remaining pairwise comparisons within commodities, but across magnitudes, were not significantly different ($p \geq .12$).

## Discussion

A few previous studies have found that cocaine-dependent individuals discount delayed hypothetical monetary gains more than nonusing controls (e.g., Coffey et al., 2003; Heil et al., 2006; Kirby & Petry, 2004). However, a comprehensive comparison of variables known to affect discounting has not been conducted with cocaine users. Therefore, by examining gains (rewards) and losses and multiple magnitudes for delay and probability discounting and by examining multiple commodities for delay discounting, in both cocaine users and matched controls, the present study constitutes the most comprehensive assessment of discounting processes in relation to cocaine use to date. There were four primary findings. First, cocaine users pervasively discounted delayed consequences more steeply than never users regardless of sign, magnitude, or commodity, with the possible exception of delay discounting of $1,000 health equivalences. Second, both groups significantly discounted delayed rewards more than losses, with a similar trend for probability discounting. Third, magnitude effects in cocaine users for delayed and probabilistic outcomes were similar to those previously observed in never users and other-drug users. Fourth, cocaine users discounted cocaine-related outcomes most steeply, with variable results comparing money and health. Each of these findings will be discussed in turn.

This is the first study to show that cocaine users discount delayed rewards more steeply than never users regardless of magnitude or commodity (with the exception of $1,000 health-related outcomes). This provides evidence of remarkably robust differences in delayed reward discounting associated with cocaine use. Previously published results from the present sample of participants also showed steeper delay and probability discounting of condom use in casual-sex scenarios in cocaine users, which com-

Table 5
*Results of ANOVA 2 for Probability Money Discounting*

| Effect | *df*s | *F* | *p* | $\eta_p^2$ |
|---|---|---|---|---|
| Cocaine use (A) | 1,43 | .007 | .934 | .01 |
| Sign (B) | 1,43 | 3.982 | .052 | .09 |
| Magnitude (C) | 2,86 | 3.706 | .029* | .08 |
| A × B | 1,43 | .039 | .845 | .00 |
| A × C | 2,86 | 3.674 | .029* | .08 |
| B × C | 2,86 | 3.459 | .036* | .07 |
| A × B × C | 2,86 | 1.52 | .224 | .03 |

*Note.* ANOVA = analysis of variance.
* $p < .05$.

Table 7
*Results of ANOVA 4 for Delay Money and Health Discounting*

| Effect | *df*s | *F* | *p* | $\eta_p^2$ |
|---|---|---|---|---|
| Cocaine use (A) | 1,44 | 7.51 | .009* | .15 |
| Sign (B) | 1,44 | 7.81 | .008* | .15 |
| Magnitude (C) | 1,44 | 14.02 | .001* | .24 |
| Commodity (D) | 1,44 | .95 | .336 | .02 |
| A × B | 1,44 | .15 | .704 | .00 |
| A × C | 1,44 | .10 | .759 | .00 |
| A × D | 1,44 | .84 | .364 | .02 |
| B × C | 1,44 | .05 | .829 | .00 |
| B × D | 1,44 | 4.70 | .036* | .10 |
| C × D | 1,44 | 5.22 | .027* | .11 |
| A × B × C | 1,44 | .39 | .533 | .01 |
| A × B × D | 1,44 | .05 | .827 | .00 |
| A × C × D | 1,44 | .03 | .864 | .00 |
| B × C × D | 1,44 | .37 | .547 | .01 |
| A × B × C × D | 1,44 | 1.35 | .252 | .03 |

*Note.* ANOVA = analysis of variance.
* $p < .05$.

Table 8
*Results of ANOVA 5 for Cocaine Users' Delay Discounting of Money, Health, and Cocaine*

| Effect | *df*s | *F* | *p* | $\eta_p^2$ |
|---|---|---|---|---|
| Sign (A) | 1,42 | 3.891 | .062 | .16 |
| Magnitude (B) | 1,42 | .058 | .812 | .00 |
| Commodity (C) | 2,42 | 15.239 | <.001* | .42 |
| A × B | 1,42 | 2.612 | .121 | .11 |
| A × C | 2,42 | .74 | .439 | .03 |
| B × C | 2,42 | 4.674 | .028* | .18 |
| A × B × C | 2,42 | .896 | .416 | .04 |

*Note*. ANOVA = analysis of variance.
* $p < .05$.



plements this evidence of robustness (Johnson, Johnson, et al., 2015). These results are also similar to previous research comparing magnitude and commodity effects between current smokers and nonsmokers. Smokers in one study showed higher discount rates across all magnitudes and commodities (Baker et al., 2003). Johnson et al. (2007) examined a light-smoking group in relation to these previous two groups, finding that light and heavy smokers did not significantly differ in discounting cigarettes or money. Cocaine use appears similar to cigarette smoking in showing robust relations with discounting processes. Assessments of such robustness have not been examined for other drugs.

This study more comprehensively extends previous research examining the sign effect in cocaine users. Previous research found a consistent sign effect in cocaine users for delayed money and cocaine outcomes (Johnson, Bruner, et al., 2015). The current study extended the robustness of the sign effect in cocaine users to health outcomes. The sign effect for delay discounting in the current study is consistent with nonusers (e.g., McKerchar, Pickford, & Robertson, 2013; Myerson, Baumann, & Green, 2017). For cocaine users, gains were discounted more steeply than losses regardless of commodity (money, health, cocaine), magnitude ($10, $100, $1,000), or process (delay or probability). This finding is also consistent with findings for smokers, who have demonstrated the sign effect for money (Baker et al., 2003; Johnson et al., 2007; but in contrast, also see Bickel, Yi, Kowal, & Gatchalian, 2008), health (Baker et al., 2003; Johnson et al., 2007), and cigarettes (Johnson et al., 2007). Interestingly, previous studies on the sign effect with money in heroin users did not detect differences in discount rates between monetary gains and losses (Cheng, Shein, & Chiou, 2012). However, it is unknown whether this is due to a difference between drugs (or the groups that use them), parametric differences between studies, or other demographics (e.g., China vs. U.S. study locations).

This is the first study to comprehensively examine magnitude effects in cocaine users. Cocaine users showed magnitude effects consistent with previous research on delayed and probabilistic outcomes with nonusers (e.g., Green, Myerson, Oliveira, & Chang, 2013; Myerson et al., 2011) and other-substance abusers (e.g., Bickel et al., 2008; Cheng et al., 2012; Mejía-Cruz et al., 2016). Delay discounting systematically decreased as the amount increased for money and health gains, and probability discounting increased as the amount increased for monetary gains. Lastly, no trend was observed in discount rates over increasing amounts of delayed or probabilistic monetary loss. In total, these data suggest that the magnitude of an outcome influences discount rates similarly for cocaine users and never users.

This study more comprehensively extends previous research on the commodity effect in cocaine users. Outcome commodity significantly influenced discount rate. Consistent with previous research (single-commodity tasks in Bickel et al., 2011; Coffey et al., 2003), cocaine gains were discounted more steeply than money gains at both $100 and $1,000 equivalents. A novel finding is that cocaine was discounted more steeply than health at the $1,000 outcome equivalents but was discounted similarly at $100 outcome equivalents. Another novel finding is that money gains and health gains were discounted similarly at $100 and $1,000 equivalents in cocaine users. This finding is consistent with previous research studying discounting across commodities in heavy smokers (Baker et al., 2003). However, light smokers were found to discount money less than health in a different study (Johnson et al., 2007), suggesting that relative rates of drug use may be associated with differential discounting of health and money outcomes. Also novel to this study were the loss comparisons in cocaine users. Cocaine was discounted most, followed by money and then health. This is the same order observed by Baker et al. (2003) with heavy smokers, but it is different from the order observed by Johnson et al. (2007) with light smokers, where cigarette-related losses were discounted least, followed by money and health. In total, these data suggest that cocaine-related outcomes are devalued most quickly as a function of delay in cocaine users, and the differences in the devaluation of money and health were specific to the unique combination of sign and magnitude in the choice context. It should be noted that steeper discounting of cocaine is likely due to the consumable nature of cocaine rather than anything particular about cocaine as a reinforcer because food and other consumable primary reinforcers are also discounted more than money (Estle et al., 2007; Friedel et al., 2016; Odum, Baumann, & Rimington, 2006; Odum & Rainaud, 2003).

One limitation to this study is a potential decreased quality of responding due to the large number of discounting questions. Reduced quality of participant responding can be estimated in two ways. One way is to examine how many participants met established criteria suggesting nonsystematic discounting (Johnson & Bickel, 2008; Johnson, Herrmann, et al., 2015). Rates of nonsystematic responding were generally favorable compared with a recent meta-analysis of nonsystematic responding for delay and probability discounting of gains (Smith, Lawyer, & Swift, 2018). All three tasks that exceeded previously reported proportions of participants meeting one or more criteria for nonsystematic discounting involved Criterion 1, and the three tasks were health-related losses of $1,000 equivalencies for the control group and both cocaine-related loss tasks for the cocaine group. A second way to estimate the quality of responding is to examine sign, magnitude, and commodity effects in control participants. Control participants showed the expected sign, magnitude, and commodity effects found in previous research. One exception was the absence of a magnitude effect for probability discounting of monetary gains. Post hoc examination of participant data failed to uncover why the magnitude effect was not observed. Nevertheless, 96% of the tasks resulted in a proportion of participants meeting criteria consistent with past literature, and sign, magnitude, and commodity effects were mostly consistent with past literature in the control group, suggesting that the large number of discounting tasks likely did not negatively affect responding.

A second potential limitation was the inclusion criteria for cocaine users. Cocaine users showed significantly higher rates of alcohol and cannabis use relative to nonusers. Poly-substance use reduces the association between patterns of discounting and cocaine use alone. Nevertheless, high rates of alcohol and cannabis use are expected in cocaine users and suggest face validity in terms of participants being representative of individuals with cocaine use disorder (CUD; e.g., Booth, Watters, & Chitwood, 1993; Coffey et al., 2003; Kirby & Petry, 2004; McCoy, Lai, Metsch, Messiah, & Zhao, 2004).

A third limitation of this study was the use of hypothetical, rather than real, outcomes. Previous research has shown generally similar results when using real and hypothetical money (e.g., Baker et al., 2003; Green & Lawyer, 2014; Johnson, 2012; Johnson & Bickel, 2002; Johnson et al., 2007; Lagorio & Madden, 2005; but in contrast, also see Hinvest & Anderson, 2010; Jikko & Okouchi, 2007) and cigarettes (Green & Lawyer, 2014; Lawyer, Schoepflin, Green, & Jenks, 2011). Thus, the observed patterns of preference for money gains in this study are likely to coincide with choices made with potentially real outcomes, and it is unclear whether it is ethically or legally possible to examine anything other than hypothetical health or cocaine outcomes, respectively. Nevertheless, no known research has compared real and hypothetical money losses, delayed health outcomes, or delayed cocaine outcomes. Thus, it is possible that our results were affected by using hypothetical health and cocaine outcomes instead of potentially real outcomes.

In conclusion, this study comprehensively and precisely described ways that cocaine users devalue outcomes. Cocaine and control groups showed similar sign, magnitude, and commodity effects for discounting tasks, suggesting that outcome devaluation is not qualitatively different between the groups. However, pervasively greater delay discount rates by cocaine users suggest that outcome devaluation as a function of delay differs quantitatively between the groups. For a current cocaine user, the moment of choice to use cocaine involves a unique interaction between a variety of contingencies that include money-, health-, and cocaine-related outcomes. Cocaine use involves a reduction in money from cocaine purchase (loss), a negative impact to health (loss), and physiological effects of cocaine consumption (gain). Abstaining from cocaine use involves an opportunity to spend that money on something else (gain), an incremental positive health impact (gain), and the negative physiological effects of abstinence (loss). Thus, the relative preferences between drug, health, and monetary gains and losses are important when considering choices made by cocaine-dependent individuals. This is particularly important for decisions to seek treatment to achieve and maintain abstinence from cocaine.

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# Appendix A

## Trials Per Task Summary

Table A1

*Maximum, 75th Percentile, Median, Mean, 25th Percentile, and Minimum Number of Trials Needed to Complete Each Discounting Task*

| Distribution value | DMG $10 | DMG $100 | DMG $1,000 | DML $10 | DML $100 | DML $1,000 | PMG $10 | PMG $100 | PMG $1,000 | PML $10 | PML $100 | PML $1,000 | DHG $100 | DHG $1,000 | DHL $100 | DHL $1,000 | DCG $100 | DCG $1000 | DCL $100 | DCL $1000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control group | | | | | | | | | | | | | | | | | | | | |
| Maximum | 118 | 144 | 109 | 124 | 138 | 131 | 117 | 127 | 123 | 162 | 125 | 138 | 114 | 293 | 99 | 301 | | | | |
| 75th | 94 | 98 | 98 | 99 | 109 | 104 | 96 | 105 | 100 | 100 | 95 | 95 | 82 | 165 | 85 | 175 | | | | |
| Median | 84 | 84 | 89 | 78 | 99 | 84 | 88 | 97 | 92 | 82 | 86 | 89 | 67 | 119 | 75 | 131 | | | | |
| Mean | 87 | 87 | 88 | 83 | 92 | 88 | 86 | 94 | 90 | 88 | 84 | 87 | 72 | 139 | 73 | 144 | | | | |
| 25th | 78 | 80 | 80 | 66 | 72 | 70 | 76 | 83 | 82 | 70 | 71 | 69 | 61 | 102 | 60 | 100 | | | | |
| Minimum | 56 | 57 | 58 | 53 | 50 | 59 | 58 | 59 | 56 | 56 | 57 | 54 | 45 | 49 | 48 | 67 | | | | |
| Cocaine group | | | | | | | | | | | | | | | | | | | | |
| Maximum | 144 | 166 | 141 | 144 | 171 | 176 | 141 | 156 | 126 | 187 | 113 | 150 | 113 | 340 | 124 | 458 | 256 | 301 | 124 | 346 |
| 75th | 110 | 109 | 104 | 99 | 102 | 112 | 106 | 101 | 100 | 95 | 95 | 99 | 86 | 178 | 88 | 238 | 123 | 193 | 76 | 150 |
| Median | 104 | 97 | 90 | 93 | 93 | 88 | 98 | 91 | 94 | 89 | 86 | 92 | 73 | 141 | 75 | 137 | 107 | 145 | 67 | 105 |
| Mean | 96 | 95 | 90 | 89 | 89 | 91 | 96 | 89 | 89 | 89 | 82 | 89 | 74 | 161 | 77 | 177 | 115 | 158 | 70 | 131 |
| 25th | 75 | 74 | 73 | 70 | 66 | 62 | 86 | 71 | 72 | 68 | 63 | 68 | 59 | 107 | 63 | 91 | 92 | 115 | 58 | 97 |
| Minimum | 53 | 56 | 64 | 50 | 57 | 54 | 47 | 51 | 56 | 52 | 53 | 57 | 48 | 82 | 56 | 82 | 64 | 75 | 50 | 87 |

*Note*. D = delay; P = probability; G = gains; L = loss; M = money; H = health; C = cocaine. The reported number of trials for each task is the number of trials needed to obtain all seven indifference points for the specified task.

(*Appendices continue*)

# Appendix B

## Controlling for Alcohol and Cannabis Covariates

Table B1

*Results From Each ANOVA When Controlling for Alcohol Abuse or Dependence and Cannabis Abuse or Dependence as Covariates*

| Effect | *df*s | *F* | *p* | $\eta_p^2$ |
|---|---|---|---|---|
| ANOVA 1: Delay discounting of money | | | | |
| Cocaine use (A) | 1,45 | 7.557 | .009* | .15 |
| Sign (B) | 1,45 | 9.59 | .003* | .18 |
| Magnitude (C) | 2,90 | 2.299 | .107 | .05 |
| A × B | 1,45 | .566 | .456 | .01 |
| A × C | 2,90 | .654 | .522 | .02 |
| B × C | 2,90 | 2.911 | .060 | .06 |
| A × B × C | 2,90 | .266 | .767 | .01 |
| ANOVA 2: Probability discounting of money | | | | |
| Cocaine use (A) | 1,43 | .096 | .758 | .00 |
| Sign (B) | 1,43 | 4.204 | .047* | .09 |
| Magnitude (C) | 2,86 | 2.023 | .139 | .05 |
| A × B | 1,43 | .000 | .983 | .00 |
| A × C | 2,86 | 2.756 | .069 | .06 |
| B × C | 2,86 | 2.503 | .095 | .06 |
| A × B × C | 2,86 | 1.350 | .265 | .03 |
| ANOVA 3: Delay discounting of health | | | | |
| Cocaine use (A) | 1,44 | 2.932 | .065 | .07 |
| Sign (B) | 1,44 | 18.493 | <.001* | .31 |
| Magnitude (C) | 1,44 | 12.487 | .001* | .23 |
| A × B | 1,44 | 1.050 | .311 | .02 |
| A × C | 1,44 | .105 | .747 | .00 |
| B × C | 1,44 | .199 | .658 | .01 |
| A × B × C | 1,44 | .884 | .352 | .02 |
| ANOVA 4: Delay discounting of money and health | | | | |
| Cocaine use (A) | 1,44 | 7.05 | .011* | .14 |
| Sign (B) | 1,44 | 13.92 | .001* | .25 |
| Magnitude (C) | 1,44 | 13.24 | .001* | .24 |
| Commodity (D) | 1,44 | 1.10 | .301 | .03 |
| A × B | 1,44 | .96 | .333 | .02 |
| A × C | 1,44 | .36 | .549 | .01 |
| A × D | 1,44 | .95 | .335 | .02 |
| B × C | 1,44 | .02 | .904 | .00 |
| B × D | 1,44 | 3.82 | .057 | .08 |
| C × D | 1,44 | 4.33 | .044* | .09 |
| A × B × C | 1,44 | .20 | .660 | .01 |
| A × B × D | 1,44 | .08 | .776 | .00 |
| A × C × D | 1,44 | .01 | .927 | .00 |
| B × C × D | 1,44 | .34 | .562 | .01 |
| A × B × C × D | 1,44 | 1.17 | .285 | .03 |

*Note*. ANOVA = analysis of variance.
* $p < .05$.

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