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Perceived reward certainty in the assessment of delay discounting

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Abstract

Reward delays are often associated with reduced probability of reward, although standard assessments of delay discounting do not specify degree of reward certainty. Thus, the extent to which estimates of delay discounting are influenced by uncontrolled variance in perceived reward certainty remains unclear. Here we examine 370 participants who were randomly assigned to complete a delay discounting task when reward certainty was either unspecified (n=184) or specified as 100% (n = 186) in the task trials and task instructions. We examined potential group differences in (a) perceived reward certainty across a range of delays, (b) delay discounting, and (c) associations between perceived reward certainty and delay discounting. Delay significantly reduced perceived reward certainty in both groups, although delay did not significantly interact with group to affect perceived certainty. Despite higher perceived reward certainty in the specified group, no significant group difference in delay discounting was observed. Higher perceived reward certainty was associated with lower delay discounting in both groups. However, we found no evidence that specifying reward certainty influences estimates of delay discounting. Future research should examine whether perceived reward certainty moderates associations between delay discounting and health behavior and whether perceived reward certainty is impacted by interventions that change delay discounting.

KEYWORDS

delay discounting, framing, perceived reward certainty, uncertainty

Delay discounting refers to the decline in subjective reward value as the delay to a reward increases (Odum, 2011). In delay discounting tasks, participants are asked to make a series of choices between smaller-sooner rewards and larger-later rewards (e.g., "Would you prefer $50 now or $100 in 2 weeks?") (Rachlin et al., 1991). Because of the association between delay discounting and behaviors with public health significance (Appelhans et al., 2019; Daugherty & Brase, 2010; MacKillop et al., 2011), it is important to understand the methodological factors that may affect estimates of delay discounting.

It has long been recognized that the perceived certainty or expectancy of a reward could decrease valuation of delayed rewards (Mahrer, 1956; Mischel & Grusec, 1967), and it is well-documented that probability influences the value of immediate rewards, with smaller certain rewards being preferred to larger uncertain rewards. Probability discounting describes the tendency for subjective reward value to decrease hyperbolically as the probability of reward receipt decreases. Given that both probabilistic rewards and delayed rewards are discounted hyperbolically, some have suggested that these processes are related or represent the same construct. For example, delay is inherent if one must respond multiple times to receive a low probability reward (which would create a delay). However, experimental manipulations (e.g., of reward magnitude) have resulted in opposite effects on delay and probability discounting, providing evidence against this hypothesis (Green & Myerson, 2010). Moreover, in factor analysis, delay and probability discounting have been shown to load on different factors, representing different constructs (e.g., Jarmolowicz et al., 2012). From an evolutionary perspective, some have suggested that the uncertainty inherent in delay may explain why organisms discount delayed rewards (Heilbronner et al., 2010; Madden & Johnson, 2010; Sozou, 1998; Stevens & Stephens, 2010; Story et al., 2016; Wilson & Daly, 1997). Delays pose collection risk by increasing the probability of events preventing reward collection (e.g., due to competition, theft), which would make preference for immediate rewards an adaptive response in uncertain environments (Green & Myerson, 1996; Stevens & Stephens, 2010). The collection risk explanation may not entirely account for why delay discounting occurs, but it is still possible that multiple mechanisms are acting simultaneously. Nonetheless, regardless of the mechanism, it is clear that both probability and delay influence reward value.

Given that lower probability results in lower reward valuation, studies have investigated how rewards in delay discounting tasks are perceived. A few studies have examined the relation between delay and perceived reward certainty. Interestingly, and proposed as a potential mechanism for hyperbolic discounting (risk inherent in delay; Sozou, 1998), perceived reward certainty has been shown to decline hyperbolically as delay increases for hypothetical rewards of various magnitudes (Białaszek et al., 2021; Takahashi et al., 2007).

Studies have also examined the relation between delay discounting and perceived reward certainty, finding negative correlations. For example, in Patak and Reynolds (2007), participants completed a delay discounting task with potentially real outcomes (i.e., one randomly selected choice was actualized) and subsequently rated the extent to which they perceived the delayed $10 reward to be certain. As delay increased, perceived reward certainty decreased and participants who perceived the reward as more certain tended to discount delayed rewards less ($r = 0.55$). These findings were replicated with hypothetical rewards by Takahashi et al. (2007), who found that the decline in perceived reward certainty was associated with degree of delay discounting of hypothetical money (rho $= 0.467$). Finding similar results with hypothetical rewards, Białaszek et al. (2021) reported negative associations of perceived reward certainty with delay discounting. Last, using potentially real rewards, Jiang and Dai (2021) built on these observational findings by experimentally manipulating perceived certainty and observing the effects of this manipulation on delay discounting. Participants were assigned to a "low-risk" group who received standard task instructions or a "high-risk" group who was told they had to remind the experimenter to receive delayed rewards. Participants in the high-risk group tended to rate the likelihood of reward receipt as lower and showed greater delay discounting than the low-risk group. Together, these observational and experimental data demonstrate that perceived reward certainty is associated with and may influence estimates of delay discounting.

Assessments of delay discounting are intended, to the extent possible, to isolate sensitivity to reward delay as their dependent variable. However, the findings above suggest that these tasks also measure uncontrolled variance in risk sensitivity and perceived reward certainty (e.g., due to individual differences in learning history, trust in the experimenter). Importantly, standard assessments of delay discounting do not often explicitly state reward certainty in task instructions, which may exacerbate confounds between sensitivity to delay and perceived reward certainty. In most methods using potentially real outcomes, participants are typically not provided any direct guidance on the probability of receiving the rewards from their randomly selected choice(s) (e.g., Madden et al., 2004; Reynolds et al., 2003). In hypothetical tasks, some guidance is provided to encourage realistic choices; however, the extent to which this guidance may address participants' perceptions about reward certainty is heterogeneous. Some hypothetical tasks indicate indirectly that participants should make decisions "as if the choices were real" (e.g., Du et al., 2002; Epstein et al., 2021; Moody et al., 2016) or "as if the rewards were real" (e.g., Field et al., 2007; Hinvest & Anderson, 2010), while others address reward certainty more directly by instructing participants to make their decisions as if they "were really going to receive these rewards [they] choose" (e.g., Odum & Rainaud, 2003; Willis-Moore et al., 2024) or "will receive the money in the time frame(s) selected" (Stein et al., 2022; Stein & Madden, 2021). To our knowledge, these instructional variants have not been systematically compared. Moreover, these references have been confined to pretask instructions and no studies have systematically examined framing of certainty in the choice options themselves, which may be even more salient than references to certainty in instructions. Gaining such an understanding is especially important, as some research has begun to explicitly examine the combined effects of probability and delay on reward valuation (Cox & Dallery, 2016; Vanderveldt et al., 2015; Yi et al., 2006), which models the naturally occurring covariance between these factors. To facilitate understanding of those interactive and more complex discounting processes, it is important to first understand whether specifying reward certainty in the delay discounting task influences choice estimates.

Clarifying reward certainty more explicitly in task instructions may produce lower estimates of delay discounting and more precisely isolate estimates of delay discounting from uncontrolled variance in perceived reward certainty. In the present study, we attempted to limit individual variability in perceived reward certainty by randomly assigning participants to complete a delay discounting task when all rewards were either specified as 100% certain (*specified group*; $n = 186$) or when degree of certainty was unspecified (as in standard instructions; *unspecified group*; $n = 184$). We compared estimates of delay discounting between groups, examined the effects of reward delay and group status on perceived reward certainty, and examined the association between perceived reward certainty and delay discounting. Consistent with prior research, we also fit a hyperbolic model to describe the relation between delay and perceived reward certainty.

METHOD

Participants

Participants were recruited using Facebook and Amazon Mechanical Turk. For Facebook, we used paid advertisements targeted at users who were 18 years of age or older and living in Virginia, USA. Clicking on either advertisement led to Part I of a two-part screening process, which was designed to minimize poor quality data and nonhuman responses (i.e., bots). To be eligible for the study, Facebook participants needed access to a valid email address. Upon entering their address in Part I of the screening survey, Qualtrics automatically sent an email to this address that included the link for Part II of the screening survey and a participant-specific, six-digit PIN. Entering the correct combination of email address and PIN in Part II granted access to the remaining four items of the eligibility screening, which required that participants to (1) report being 18 years of age or older; (2) pass a *No CAPTCHA reCAPTCHA* response item (Shet, 2014); (3) accurately classify verbs and nonverbs from a list of 18 English words (six verbs, six nouns, and six adjectives) with a score of at least 17 out of 18; and (4) not have an IP address associated with previous attempts to screen for the study, locations outside the United States, or a virtual private network (VPN, which may be used to mask location).

Amazon Mechanical Turk workers were recruited as described above, with the following exceptions. Participants on Amazon Mechanical Turk were not required to provide an email address because Amazon Mechanical Turk itself served as the survey distribution method. Moreover, Item 3 described above (verb identification) was replaced with the requirement that Amazon Mechanical Turk workers' approval rating for prior surveys was ≥ 95%.

Despite this difference, responses from Amazon Mechanical Turk workers had a similar median survey duration as individuals recruited on Facebook. The screening survey may be found as supplementary material on the Open Science Framework (OSF) platform (https://osf.io/er7ya/?view_only=1bef8215498c4523ab04665479c3a568).

Figure 1 depicts participant flow from eligibility assessment through study completion and data analysis. A total of 393 participants were eligible for the survey, with 14 participants stopping the survey prior to randomization. In total, 379 participants were randomly assigned to complete the delay discounting task with reward certainty specified as 100% (specified group; $n = 190$) or

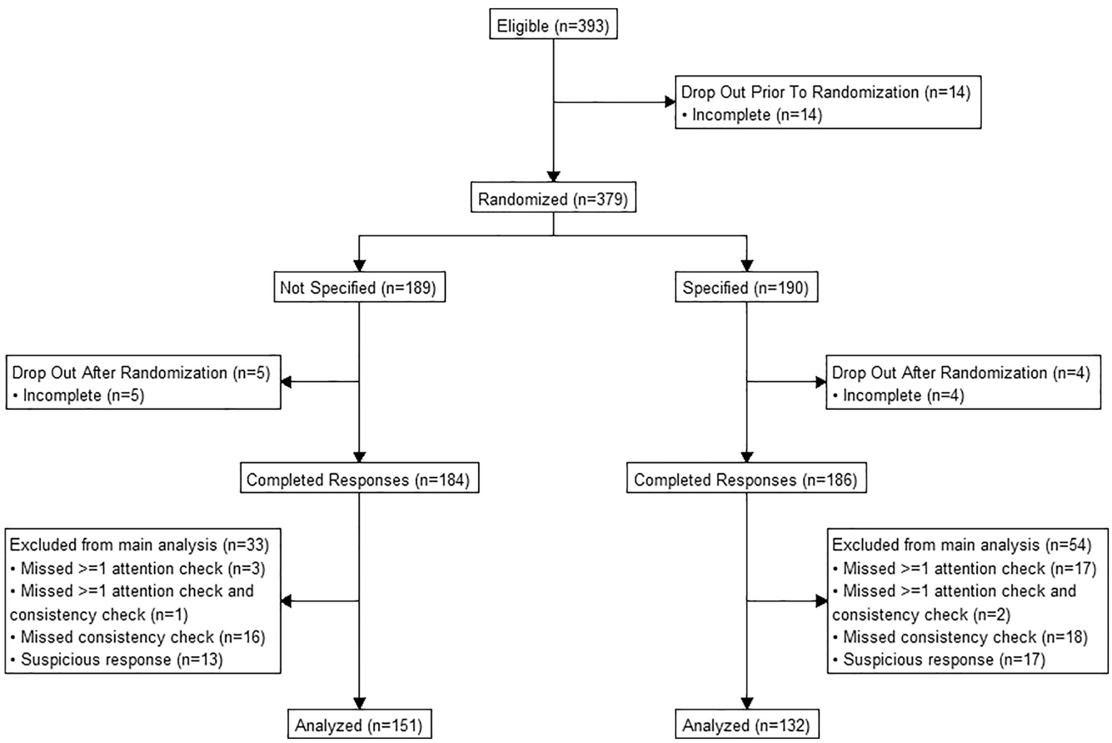

FIGURE 1 Flow diagram depicts the numbers of participants who were eligible, started the survey, were randomized to groups, completed the survey, and were included in analyses.

unspecified (unspecified group; $n = 189$). Nine randomized participants did not complete the survey, leaving 370 completed responses. Finally, 87 complete responses were excluded from main analyses due to data quality concerns (see Figure 1).

Participants recruited from Facebook received a $2 Amazon eGift Card for completing the survey, which required a median time of 4.8 min (effective hourly wage: $25/hr). Similarly, participants recruited from Amazon Mechanical Turk were paid $2 for completing the survey, which required a median time of 5.2 min (effective hourly wage: $23.08/h). The study was conducted in September and October, 2022. More details may be found in Supplementary Figure 1 (https://osf.io/er7ya/?view_only=1bef8215498c4523ab04665479c3a568).

The final analytic sample (N = 283) provided 95% power to detect an approximately small–medium effect size or greater ($f^2 > 0.082$) in multiple linear regression, assuming three predictors and $\alpha = .01$ to account for multiple testing. A Bonferroni correction for six comparisons yielded an adjusted $\alpha = .0083$, which rounds to .01. Thus, for simplicity and interpretability, we used a threshold of $\alpha = .01$.

Procedure

This research was approved by the Virginia Tech IRB and performed in accordance with the 1964 Declaration of Helsinki. Participants completed the experiment online using Qualtrics survey software. Eligible participants provided informed consent by reading an IRB-approved consent information sheet and indicating their agreement; acquiring written informed consent was waived by the IRB. The survey consisted of a demographic questionnaire, a delay discounting task, and an assessment of participants' perceived reward certainty relevant to the delay discounting task.

Demographics questionnaire

Participants reported age, household income, education, race, ethnicity, gender, and other demographic characteristics.

Delay discounting

The six-trial adjusting-delay task (Koffarnus et al., 2021; Stein et al., 2022) was used to assess delay discounting. This task is a recent modification of the validated five-trial adjusting-delay task (Koffarnus & Bickel, 2014), with a sixth trial added to increase the range and resolution in measurement of delay discounting. Before completing the task, participants read the instructions in Figure 2. The text for the unspecified group is identical to the instructions for the standard version of the task (Koffarnus & Bickel, 2014) and is consistent with instructions used previously (Du et al., 2002; Madden et al., 2003).

Subsequently, participants made repeated, hypothetical choices between receiving either $1,000 after a delay or $500 immediately (position on screen randomized on every trial). Importantly, in the specified group, the words "100% chance of" preceded both reward amounts in every trial. In the unspecified group, only the amounts appeared (see Figure 2). The delay to the larger amount started at 3 days on the first trial and was adjusted following each trial, based on the preceding choice. Specifically, choices for the larger amount increased the delay and choices for the smaller amount decreased the delay. The adjusted value after the final trial serves as a measure of effective delay 50 (ED50) (Yoon & Higgins, 2008), or the delay required to reduce subjective value by 50%. ED50 in this task spans 64 possible values, ranging from approximately 26 s to 52 years in approximately logarithmic intervals. Higher ED50 values reflect less discounting (i.e., greater valuation) of the delayed outcome. Besides attention checks (see Data quality section), all other procedures in these trials were identical to those outlined for the six-trial adjusting-delay task, including specification of certainty. Supplementary Table 1 (https://osf.io/er7ya/?view_only=1bef8215498c4523ab04665479c3a568) includes additional task details, including delays, branching logic, and ED50 scoring methods.

Perceived reward certainty

Following the six-trial adjusting-delay task, participants used a visual analog scale (VAS) to rate perceived reward certainty. Prior to the task, participants read the following instructions:

> In some of the prior questions, you were asked to choose between receiving $500 NOW and $1000 after a DELAY. We are interested in the different ways these questions can be interpreted. Below are some questions you may have seen earlier in the survey. If you were to choose the $1,000 option, please rate how CERTAIN you are that you would receive the $1,000. Please use a scale from 0 (definitely would NOT receive) to 100 (definitely WOULD receive). Your answers should reflect your own interpretation of these questions.

Next, participants were presented with reference trials from the six-trial adjusting-delay task structured identically to those seen earlier (i.e., for the specified group, "100% chance of" preceded the reward amount). For each of these reference trials, participants were asked the following question:

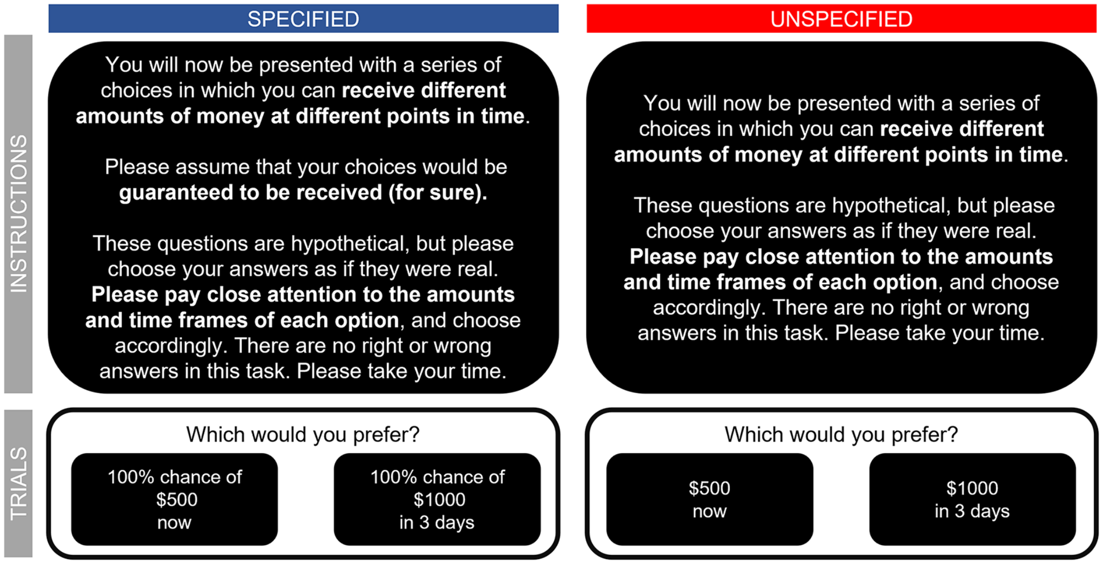

FIGURE 2 Instructions and presentation of choice trials for each specification group. The left side is for the specified group, and the right side is for the unspecified group. The top shows instructions and the bottom shows example trials.

> If you had chosen the $1,000 option in the question above, how certain are you that you would receive the money? Please assume this choice was real (not hypothetical).

This question was repeated at each of seven delays to the larger reward ("now", 1 month, 3 months, 10 months, 3 years, 8 years, and 26 years), in ascending order and on the same page. These specific delays, chosen from among the possible delays presented in the six-trial adjusting-delay task, are approximately logarithmically scaled and span more than 95% of observed participants' ED50 values observed in prior uses of the five- and six-trial adjusting-delay tasks (Koffarnus & Bickel, 2014; Stein et al., 2017, 2018, 2021; Stein & Madden, 2021).

Data quality

We examined the quality of submitted responses in three ways. First, we used a consistency check and asked participants the same question (about job responsibilities) two times. Participants who reported different job responsibilities across the survey were excluded. Next, for Facebook participants, we examined a postsurvey comment box, submission time of day, and device information (e.g., browser, obtained from a metadata response item), as has been recommended previously (Griffin et al., 2021; Storozuk et al., 2020). We excluded 30 responses that had identical comments, the same screen size, and the same internet browser. Further, examining the email addresses provided by these 30 respondents revealed similar combinations of first and last name (e.g., doejohn@email.com, johndoe@email.com). The last way we assessed data quality was attention checks embedded in delay discounting tasks. Because the six-trial adjusting-delay task does not allow use of standardized diagnostic criteria to assess orderliness of obtained data (see e.g., Johnson & Bickel, 2008), two quality control questions were embedded in the task, similar to those used previously (Craft et al., 2022; Stein et al., 2018; Stein & Madden, 2021; Vaughn et al., 2021). Specifically, one quality-control trial asked participants to choose between $0 now and $1000 now and the other asked participants to choose between $500 now and $0 now. Choice of the $0 option in either trial was interpreted as inattention. Participants that missed any attention check were excluded from the main analysis reported in text. Analyses were performed again with all excluded data (see Supplementary Tables 7-13).

Statistical analysis

Participant characteristics. Demographic characteristics were summarized for the overall sample and by specification group using means, standard deviations, medians, interquartile ranges, and ranges for continuous variables, and frequencies and percentages for categorical variables. Group comparisons of participant characteristics relied on two-sample *t*tests, Fisher's exact tests or chi-squared tests, as appropriate. Cohen's *d* and Cramer's *V* effect sizes were also conducted to interpret the findings' clinical significance and relevance.

Perceived reward certainty (PRC). We explored the use of different outcome measures to describe perceived reward certainty across delays. We originally considered the median perceived reward certainty due to skewness, but considered other outcomes at the suggestion of reviewers. The other measures we examined were the mean perceived reward certainty, area under the curve (AUC; Myerson et al., 2001), ordinal AUC (Borges et al., 2016), and log-transformed k_{PRC} values from Mazur's (1987) hyperbolic equation. We adapted Mazur's (1987) hyperbolic equation,

$$Perceived\ reward\ certainty = \frac{A}{1 + k_{PRC}D},$$

where A is the amount of the reward, D is the delay in days, and k_{PRC} is a free parameter that can be interpreted as the degree of decline in perceived reward certainty. We used individual ratings of perceived reward certainty. Because some participants did not have any decline in perceived reward certainty (i.e., their perceived reward certainty at 26 years was 100), we subtracted 0.01 from the perceived reward certainty for 26 years for those individuals so that nonlinear models could be fit for each participant, as has been suggested previously (Johnson & Bickel, 2008). We calculated the root mean square error as an index of model fit. We explored potential group differences in k_{PRC} values for models fit with individual-level data using t tests.

To examine the systematicity of perceived reward certainty as a function of delay, we applied methods used to examine systematicity of delay discounting indifference points, which may be justified because other studies have found that perceived reward certainty declines hyperbolically. Specifically, we used Criterion 1 from Johnson and Bickel (2008) under the assumption that delay should result in declines in perceived reward certainty at every delay (i.e., perceived reward certainty should not increase more than 20% from one delay to the next). We did not examine Criterion 2, which deals with the assumption that perceived reward certainty should decline overall from the first to last delay, because the specification manipulation could result in sustained high levels of perceived reward certainty. We describe the systematicity of perceived reward certainty overall and by group using percentages. To facilitate comparison with previous studies, we also report the correlation between perceived reward certainty outcome measures and delay discounting.

Effects of specification group and delay on perceived reward certainty. Linear mixed-effects modeling was performed to account for repeated measures in a single participant. For this model, perceived reward certainty was regressed on specification group, amount of delay in months (0, 1, 3, 10, 36, 96, and 312), and their interaction (Group x Delay).

Effects of specification group on delay discounting. We used Levene's test to assess homogeneity of variance for delay discounting for the two groups. General linear regression models were used to quantify the effect of group on delay discounting as well as the effect of specification group, median perceived reward certainty, and their interaction (Group x Median Perceived Reward Certainty) on delay discounting. This analysis was repeated with the mean perceived reward certainty and the ordinal AUC for perceived reward certainty (see Supplemental Materials). To examine the influence of demographic covariates on the modeling results, models were also performed when adjusting for demographic covariates using a stepwise approach. For general linear models, demographic variables that improved the proportion of the variance explained by the model adjusted for the number of independent variables in each model (model-adjusted R^2) were retained. For linear mixed-effects models, demographic variables were retained if they improved the overall Akaike information criteria (AIC), a measure of model prediction error where smaller values are indicative of better model fit.

All analyses were performed twice, once with included participants (see main text) and once with excluded participants (see Supplemental Materials). All analyses were performed using R statistical software (version 4.3.1) and SAS V9.4 (SAS Institute Inc., Cary, NC).

RESULTS

Participant characteristics

Table 1 summarizes demographic characteristics for the overall sample and by specification group. Randomized participants were 39.43 (±12.72) years old on average, about half were women (51.9%), and a majority were White (82.7%), non-Hispanic (89.8%), with household income of < \$100,000/year (75.3%), and ≥ 2-year college education (73.2%). No statistically significant differences were observed between the two groups. In total, 119 participants were from Facebook and 164 participants were recruited from Amazon Mechanical Turk.

Effects of group and delay on perceived reward certainty

Figure 3 depicts individual- and group-level data for perceived reward certainty across increasing delays. Table 2 and Supplementary Table 2 provide unadjusted and adjusted linear mixed effects modeling results for perceived reward certainty regressed on specification group, amount of delay, and their interaction. Unadjusted modeling results demonstrated that for each month increase in delay, across the entire sample, perceived reward certainty decreased by 0.14 ($p < .0001$). Overall, the specified group reported perceived reward certainty 9.72 VAS units higher than the unspecified group ($p = .005$). The interaction between delay and specification group was not significant ($p = .916$), indicating that there was no evidence that the difference in perceived reward certainty across groups depended on delay. Findings were similar when adjusting for gender and income (Supplemental Table 1).

TABLE 1 Summary of demographic characteristics.

			Specification group			
		Overall sample (N = 283)	**Unspecified (*N* = 151)**	**Specified (*N* = 132)**	***p****	**Effect size****
Age	*n*	282	151	131	.419	.097
	Mean	39.43	40.00	38.77		
	SD	12.72	12.40	13.09		
	Median	37.00	37.00	36.00		
	Q1, Q3	30.00, 48.00	30.00, 51.00	29.00, 46.00		
	Min, Max	18.00, 75.00	18.00, 75.00	18.00, 69.00		
Gender, n (%)	Female	147 (51.9%)	83 (55.0%)	64 (48.5%)	.069	.137
	Male	132 (46.6%)	68 (45.0%)	64 (48.5%)		
	Nonbinary / third gender	4 (1.4%)		4 (3.0%)		
Race, n (%)	Multiracial	12 (4.2%)	7 (4.6%)	5 (3.8%)	.673	.074
	Black	17 (6.0%)	8 (5.3%)	9 (6.8%)		
	White	234 (82.7%)	123 (81.5%)	111 (84.1%)		
	Other	20 (7.1%)	13 (8.6%)	7 (5.3%)		
Hispanic/Latino, n (%)	No	254 (89.8%)	134 (88.7%)	120 (90.9%)	.549	.036
	Yes	29 (10.2%)	17 (11.3%)	12 (9.1%)		
Education, n (%)	Some High School	1 (0.4%)	1 (0.7%)		.683	.105
	High School Graduate/Equivalent	25 (8.8%)	12 (7.9%)	13 (9.8%)		
	Some College	50 (17.7%)	24 (15.9%)	26 (19.7%)		
	College Graduate/2-year Degree	24 (8.5%)	15 (9.9%)	9 (6.8%)		
	College Graduate/4-year Degree	137 (48.4%)	72 (47.7%)	65 (49.2%)		
	Graduate or Professional Degree	46 (16.3%)	27 (17.9%)	19 (14.4%)		
Income, n (%)	$0 to $49,999	91 (32.2%)	46 (30.5%)	45 (34.1%)	.178	.149
	$50,000 to $99,999	122 (43.1%)	63 (41.7%)	59 (44.7%)		
	$100,000 to $149,999	47 (16.6%)	32 (21.2%)	15 (11.4%)		
	$150,000 to $199,999	14 (4.9%)	5 (3.3%)	9 (6.8%)		
	$200,000 or more	9 (3.2%)	5 (3.3%)	4 (3.0%)		

Note: *SD*: standard deviation; Q1: first quartile; Q3: third quartile; Min: minimum; Max: maximum; **p* values are based on two-sample *t* tests for age and Fisher's exact test or chi-squared test for all categorical variables; **Effect sizes are based on the Cohen's *d* (small: .20, moderate: .50, large: .80) for age and Cramér's *V* (small: .10, moderate: .30, large: .50) for all other variables.

Higher income and gender were directionally associated with higher perceived reward certainty (higher perceived reward certainty in those with higher income and reporting male gender), although these associations were not significant according to our significance threshold of .01.

We also explored the relation between perceived reward certainty and delay by group by adapting Mazur's (1987) equation. For equations fit to individual-level data, the unspecified group had higher mean ln (k_{PRC}) (M =-7.86; $SD = 3.53$) than the specified group (M =-9.46; $SD = 4.45$; t = -3.28; $p = .001$). The mean root mean square error for the unspecified group was 13.40 and for the specified group was 8.75.

Systematicity. Overall, $n = 30$ (10.6%) of participants were flagged for violating Criterion 1, and this did not significantly differ by group (n = 11 and 19 in the specified and unspecified groups, respectively) according to a Fisher's exact test ($p = .33$).

Effects of group on delay discounting

Table 3 and Supplementary Table 3 provide corresponding unadjusted and adjusted general linear modeling results. Unadjusted models showed that the participants in the specified group on average have less delay discounting (i.e., ln(ED50) of 0.73 greater) than the participants in the unspecified group, although not statistically significant ($\beta = 0.73$, $p = .115$). See Figure 4. Results were consistent when adjusting for education, ethnicity, race, and income (Supplementary Table 3). The Levene's test for homogeneity of variance for delay discounting for the two groups was not significant ($p = .749$).

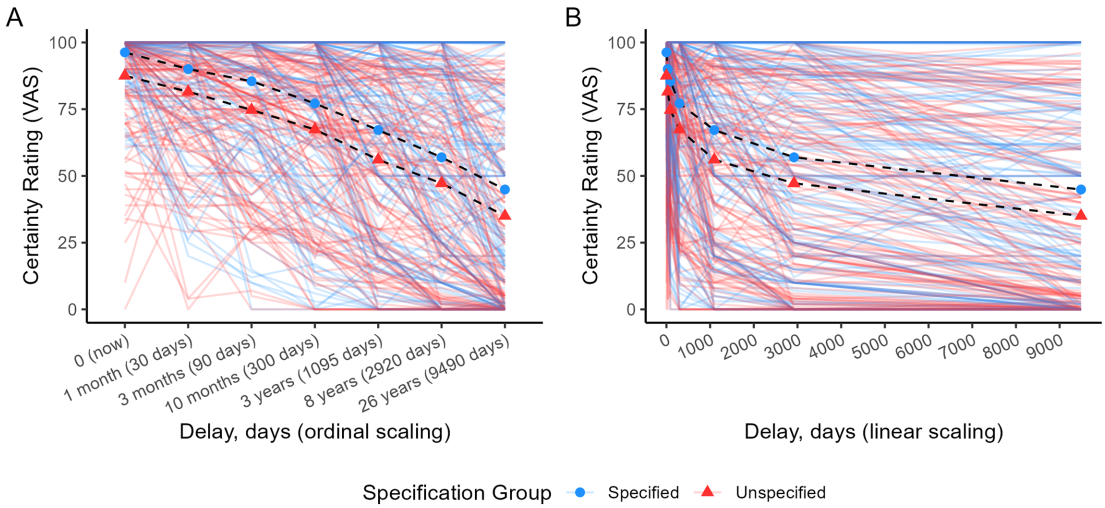

FIGURE 3 Certainty rating by delay for specified and unspecified group. Individual data are presented with blue and red lines. Red triangle points (unspecified) and blue regular points (specified) and dashed lines represent group means. Panel A shows delays ordinally, with equal spacing between delays. Panel B presents delays linearly.

TABLE 2 Unadjusted linear mixed effects modeling results for perceived reward certainty on specification group, amount of delay and their interaction.

Outcome	Predictor	Level	Estimate (95% CI)	*F*	*p*
Perceived reward certainty	Specification Group	Specified vs. Unspecified (REF)	9.72 (4.24, 15.19)	12.12	.0005
	Delay		-0.14 (-0.15, - 0.13)	838.59	<.0001
	Delay * Specification Group	Specified vs. Unspecified (REF)	0.001 (-0.02, 0.02)	0.01	.916

Note: REF: Reference; CI: Confidence Interval.

TABLE 3 Unadjusted general linear model results for natural log of ED50 on specification group.

Outcome	Predictor	Level	Estimate (95% CI)	*F*	*p*
ln (ED50)	Specification group	Specified vs. Unspecified (REF)	0.73 (-0.18, 1.65)	2.50	.1152

Note: REF: Reference; CI: confidence interval.

TABLE 4 Means, standard deviations, and spearman correlations for perceived reward certainty outcomes and delay discounting.

Variable	*M*	*SD*	1	2	3	4	5
1. Perceived Reward Certainty- ln(*k*)	-8.61	4.10					
2. Perceived Reward Certainty- Median	72.72	30.18	-.79***				
3. Perceived Reward Certainty- Mean	68.78	23.38	-.96***	.89***			
4. Perceived Reward Certainty– Ordinal AUC	0.69	0.24	-.95***	.9***	1***		
5. Perceived Reward Certainty- AUC	0.50	0.34	-.97***	.74***	.94***	.92***	
6. Delay discounting- ln(ED50)	4.13	3.90	-.18**	.39***	.28***	.31***	.14*

Note: AUC is area under the delay discounting curve. ln(ED50) is the natural log of effective delay 50.

Associations between perceived reward certainty and delay discounting

Descriptive statistics for the various summary measures of perceived reward certainty and correlations between these outcomes and delay discounting are in Table 4. All perceived reward certainty outcomes were highly correlated (absolute value of Spearman rho from .74 to 1.00), but distributions varied (see Supplementary Materials). All perceived reward certainty measures were significantly correlated with ln ED50 (higher perceived reward certainty was associated with higher ln ED50).

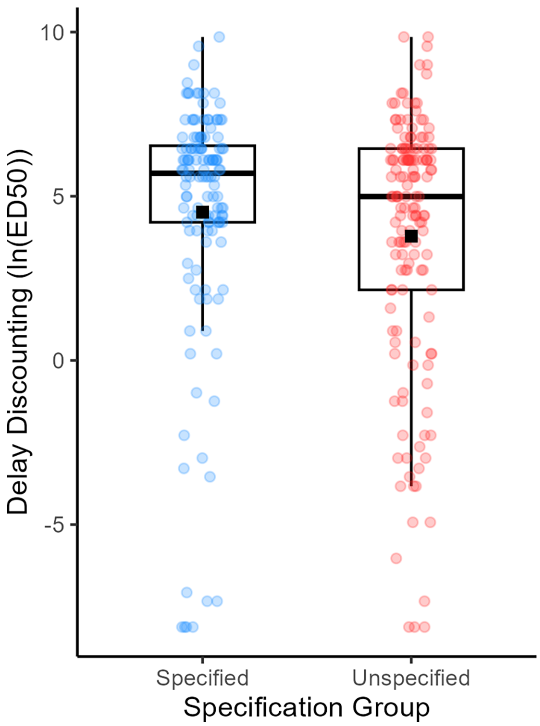

FIGURE 4 Delay discounting by specification group. Individual data are represented by circless, and the group mean is represented by squares. Higher values reflect less discounting. The upper whisker extends from the third quartile to no more than 1.5 times the interquartile range (IQR) above the third quartile. The lower whisker extends from the first quartile to no less than 1.5 IQR below the first quartile.

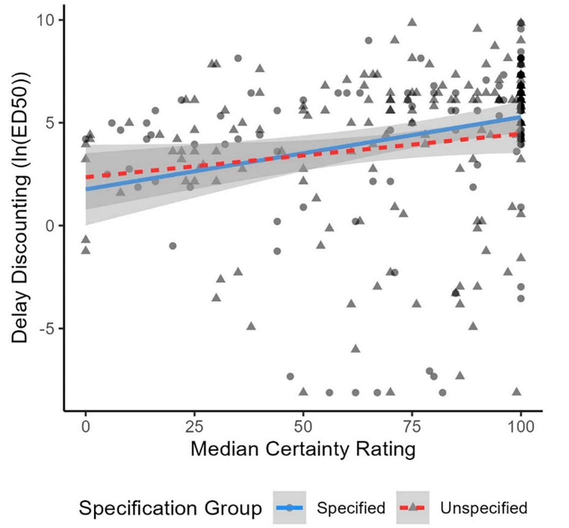

FIGURE 5 Median perceived reward certainty and delay discounting by specification group. Individual points are in black (triangles for unspecified, circles for specified), with darker points representing more points at that value. Lines represent general linear model predictions by specification group (red dashed line for unspecified, blue solid line for specified).

Table 5 and Supplementary Table 4 provide unadjusted and adjusted general linear modeling results for delay discounting (natural log of ED50) on specification group, median perceived reward certainty, and their two-way interaction. No statistically significant interaction of median perceived reward certainty and specification group was observed ($\beta = 0.01$, $p = .360$; see Figure 5. Findings were similar when adjusting for ethnicity, education, race, and income (Supplementary Table 4) and when using mean perceived reward certainty or ordinal AUC for perceived reward certainty as predictors instead of the median (Supplementary Table 5 and 6).

DISCUSSION

The present study sought to examine how specifying reward certainty influences estimates of perceived reward certainty and delay discounting. Overall, delay decreased perceived reward certainty (main effect of delay) and specifying that rewards were certain in the specified group increased perceived reward certainty relative to the unspecified group (main effect of group). However, we observed no significant interaction between specification group and delay, indicating similar declines in perceived reward certainty as a function of delay in both groups. We described the decline in perceived reward certainty using a hyperbolic model, providing some additional support (Białaszek et al., 2021; Takahashi et al., 2007) for the idea that risk is inherent in delay and that the hyperbolic decline in perceived certainty could contribute to delay discounting (Sozou, 1998); however, testing other models was outside the scope of the present study. Overall, higher perceived reward certainty was associated with lower delay discounting, which replicates prior findings (Białaszek et al., 2021; Patak & Reynolds, 2007; Takahashi et al., 2007). However, the strength of the relation was not significantly differentiated between groups (i.e., no significant interaction between perceived reward certainty and group). Finally, estimates of delay discounting did not significantly differ between groups. In sum, despite higher perceived reward certainty overall in the specified compared to unspecified group, both groups showed similar (a) effects of delay on perceived reward certainty, (b) associations between perceived reward certainty and delay discounting, and (c) absolute level of delay discounting.

The absence of a group effect on delay discounting is unexpected, given the observed relation between perceived reward certainty and delay discounting and the (apparently) successful manipulation of perceived reward certainty in the present study. Below, we highlight at least three considerations that may account for this null effect of group on delay discounting. First, the instructional manipulation increased perceived certainty (significant main effect of group), but it did so across independently of delay (no significant Group x Delay interaction; see Figure 3)—including when the larger reward was

TABLE 5 Unadjusted general linear model results for natural log of ED50 on Specification group, median perceived certainty and their interaction.

Outcome	Predictor	Level	Estimate (95% CI)	*F*	*p*
ln (*ED50*)	Median Perceived Certainty		0.02 (0.0003, 0.04)	0.24	.0003
	Specification Group	Specified vs. Unspecified (REF)	-0.59 (-2.98, 1.80)	13.52	.63:
	Median Perceived Certainty * Specification Group	Specified vs. Unspecified (REF)	0.01 (-0.02, 0.04)	0.84	.36

Note: REF: r(eference; CI: confidence interval.

available immediately. Thus, it is possible that the manipulation affected the certainty of both rewards in the task (smaller-sooner and larger-later) rather than just the larger-later rewards, which would result in similar relative values of the immediate and delayed reward across groups. Experimental manipulations of perceived reward certainty may affect delay discounting when altering perceived reward certainty for delayed but not immediate rewards (compared to both, simultaneously). This differential effect would provide a clearer mechanism to systematically shift choice between delayed and immediate rewards, compared to the universal shift in perceived reward certainty at all delays as observed in the present study.

Second, it is possible that specifying reward certainty in the delay discounting task exerts real, but smaller than expected, effects on delay discounting. Analyses were powered to detect a small to medium effect size of specification group on delay discounting, which is conservative considering the medium to large effect sizes on delay discounting reported by Jiang and Dai's (2021) alternative perceived reward certainty manipulation. If the present study's instructional manipulation exerts an actual effect on choice, this effect may be much smaller than anticipated. Indeed, the observed difference in delay discounting between groups was in the expected direction (lower delay discounting for the specified group), but in the very small range ($d = .19$). Alternatively, if perceived reward certainty manipulations in general can alter delay discounting, it is possible that simply specifying reward certainty in the delay discounting task does not exert a large enough influence on perceived reward certainty to observe corresponding effects on delay discounting.

Third, and finally, it is possible that there is no causal relation between perceived reward certainty and delay discounting. In this case, the observed correlation between delay discounting and perceived certainty would be due to a third variable (e.g., previous experience with uncertain outcomes) linking the two. Although not significant, higher income (which has been negatively associated with delay discounting; Keidel et al., 2021) and gender were associated with higher perceived reward certainty, which may support this explanation.

Direct evaluation of these possibilities awaits further research. Nonetheless, we conclude that the instructional manipulation investigated in the present study (i.e., specifying rewards as certain in task instructions and response options) has little to no effect on estimates of delay discounting. This point notwithstanding, future research should systematically investigate the conditions under which this or other experimental manipulations of perceived reward certainty produce corresponding changes in delay discounting as well as the relations between individual difference variables and perceived reward certainty. We note that the study by Jiang and Dai (2021) serves as the only other investigation to our knowledge to experimentally manipulate perceived reward certainty, and several methodological differences limit the extent to which those findings can inform the present results. Namely, these authors experimentally *decreased* perceived reward certainty and observed expected increases in delay discounting, whereas the present study investigated whether increasing perceived reward certainty would decrease delay discounting. Likewise, these authors did not explicitly test for a group by delay interaction effect on perceived reward certainty, as in the present study. These or other methodological differences (e.g., real vs. hypothetical rewards) limit direct comparison to the present study's findings. Future research should investigate whether perceived reward certainty manipulations or their effects on delay discounting are moderated by any of these factors. Perhaps there are limits to the effect that increasing certainty can have on delay discounting, whereas decreases in perceived reward certainty may have greater potential to influence delay discounting. In addition, compared to the undergraduate population recruited by Jiang and Dai, recruiting from the general population is likely to produce greater heterogeneity in socioeconomic status and other factors, including household chaos and unpredictability, that may cause an individual to learn that delayed rewards are unlikely to materialize. These individual differences have been associated with greater delay discounting (Martinez et al., 2022; Peviani et al., 2019) and may make it more difficult to modify perceived reward certainty and delay discounting with a brief framing manipulation when there are other, potentially stronger factors at play.

Limitations

There are a few methodological considerations for interpreting results of this study. First, in order to implement the manipulation, we had to communicate to participants in the specified group that rewards were both hypothetical *and* certain. This language might have been confusing for some participants and may have affected the results. Despite this consideration, no evidence of such confusion is apparent in the mostly orderly effects of delay and specification group on perceived reward certainty, suggesting participants understood task instructions. Nonetheless, future research may consider evaluating comprehension of instructions when specifying certainty with hypothetical rewards.

Second, we did not collect perceived reward certainty for the smaller-sooner outcome, which may have helped interpret the results. However, perceived reward certainty for the larger reward was collected across a broad range of delays as well as for immediate rewards, which provides some basis to extrapolate to all rewards. Moreover, a previous study found no difference in perceived reward certainty for large and small rewards available now (Białaszek et al., 2021). Nonetheless, future research should evaluate perceived reward certainty for both larger-later and smaller-sooner rewards to further understand the influence of perceived reward certainty manipulations.

Third, and finally, interpretation of the present results is restricted to the use of an adjusting-delay task to assess delay discounting. Degree of delay discounting measured by adjusting-delay and adjusting-amount tasks are correlated (Koffarnus & Bickel, 2014; Stein et al., 2021) and are sensitive to the same experimental variables (Stein et al., 2017; Vaughn et al., 2021). Nevertheless, we recommend that future studies examining this effect use a longer adjusting-amount task to yield more precision in estimating degree of delay discounting, which may reduce variability and yield important information about effects of the manipulation on the shape of the delay discounting curve.

Conclusions

Specifying reward certainty in task instructions appears to have a minimal influence on estimates of delay discounting measured using the six-trial adjusting-delay task. Still, results of the present and prior studies have consistently found that perceived reward certainty decreases with increasing delay and that variability in perceived reward certainty is associated with delay discounting. This suggests that perceived reward certainty contributes to delay discounting and, moreover, that uncontrolled variance in perceived reward certainty introduces extraneous variability into estimates of delay discounting. However, task instructions regarding reward certainty do not appear to be contributing to this association. Future research is needed to test if other methods of increasing reward certainty affect delay discounting.

Given the evidence here and found previously that perceived reward certainty is associated with delay discounting, we recommend that future research further examine the effects of specifying reward certainty in assessments of delay discounting. Better understanding of the factors that influence perceived reward certainty could inform research examining the combined effects of delay and probability on decision making (Cox & Dallery, 2016; Vanderveldt et al., 2015; Yi et al., 2006). Perceived reward certainty should also be investigated as a moderator of the relation between health behaviors and delay discounting (see e.g., Reynolds et al., 2007) and as a mediator in interventions that have been shown to change delay discounting, like episodic future thinking (Rung & Madden, 2018).

AUTHOR CONTRIBUTIONS

Haylee Downey: Conceptualization; Writing – original draft; Writing – review & editing; Visualization. Alicia Alvarez: Formal analysis. Wenyan Ji: Formal analysis. Alicia Lozano: Formal analysis. Alexandra Hanlon: Supervision; Funding acquisition. Jeffrey S. Stein: Conceptualization; Funding acquisition; Writing – original draft; Writing – review & editing; Methodology; Project administration; Supervision; Resources.

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CONFLICT OF INTEREST STATEMENT

None of the authors have a conflict of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Open Science Framework at https://osf.io/26tu4/?view_only=6ba8ef1257af410ba6fa1e901448933d.

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