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Using Crowdsourcing to Examine Relations Between Delay and Probability Discounting

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Abstract

Although the extensive lines of research on delay and/or probability discounting have greatly expanded our understanding of human decision-making processes, the relation between these two phenomena remains unclear. For example, some studies have reported robust associations between delay and probability discounting, whereas others have failed to demonstrate a consistent relation between the two. The current study sought to clarify this relation by examining the relation between delay and probability discounting in a large sample of internet users (n= 904) using the Amazon Mechanical Turk (AMT) crowdsourcing service. Because AMT is a novel data collection platform, the findings were validated through the replication of a number of previously established relations (e.g., relations between delay discounting and cigarette smoking status). A small but highly significant positive correlation between delay and probability discounting rates was obtained, and principal component analysis suggested that two (rather than one) components were preferable to account for the variance in both delay and probability discounting. Taken together, these findings suggest that delay and probability discounting may be related, but are not manifestations of a single component (e.g., impulsivity).

Keywords

Delay Discounting; Probability Discounting; Crowdsourcing; Amazon Mechanical Turk; Monetary Choice Questionnaire; Human

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1 Introduction

When choosing between reinforcers that vary in both their magnitude and immediacy, participants typically prefer more immediate reinforcers, even if they are smaller than the delayed reinforcers (i.e., delayed reinforcers are devalued). This devaluation process (i.e., delay discounting [DD]) is mathematically described by Mazur's (1987) formula,

$$\mathrm{V}=\mathrm{A}/1+k\mathrm{D},$$

where the subjective value (V) of a particular amount (A) of a reinforcer is a function of the DD rate (*k*) and delay duration (D). The formula's only free parameter, *k*, often serves as a shorthand description of this process (i.e., DD). Research on DD has contributed to our understanding of decision-making deficits seen in many clinical and non-clinical populations (see, Bickel and Marsch 2001; Bickel et al. 2012; Madden and Bickel 2009; Reynolds 2006, for reviews).

Similarly, when choosing between reinforcers that differ in both magnitude and certainty, participants typically prefer certain to probabilistic reinforcers. Like the magnitude/delay tradeoffs in DD, this preference entails trade-offs between magnitude and certainty. This phenomenon, called probability discounting (PD), is mathematically described by a modification of Mazur's (1987) formula (Rachlin, Raineri, and Cross 1991),

$$\mathrm{V}=\mathrm{A}/1+h^{\Theta},$$

where the subjective value (V) of a given amount (A) of a reinforcer is a function of the PD rate (*h*) times the odds against receiving the reinforcers ($^{\Theta}$). The value of the one free parameter, *h*, can be used as a shorthand description of this pattern of responding. Research on PD has expanded our understanding of clinical populations, particularly problem gambling (Andrade and Petry 2012; Holt, Green, and Myerson 2003; Madden, Petry, and Johnson 2009; Petry 2011).

Although both DD and PD research have advanced our understanding of decision-making, the relation between these processes remains unclear. Individuals hyperbolically discount probabilistic reinforcers (e.g., Rachlin, Raineri, and Cross 1991; Yi, de la Piedad, and Bickel 2006), delayed reinforcers (e.g., Yi, de la Piedad, and Bickel 2006; Bickel, Odum, and Madden 1999), and reinforcers that are both probabilistic and delayed (Yi, de la Piedad, and Bickel 2006). DD and PD, however, are dissimilarly impacted by variables such as reinforcer magnitude (Green, Myerson, and Ostaszewski 1999; Myerson, Green, and Morris 2011; Yi, de la Piedad, and Bickel 2006) and valance (Estle et al. 2006), suggesting that they may be distinct processes (Myerson, Green, Hanson, Holt, Estle, 2003). Moreover, although some studies have reported large and significant correlations between DD and PD (Mitchell 1999; Richards et al. 1999; Holt, Green, and Myerson 2003), other studies have failed to demonstrate this relation (Holt, Green, and Myerson 2003; Madden, Petry, and Johnson

2009; Olsen et al. 2007; Petry 2011; Reynolds et al. 2004; Shead and Hodgins 2009). Studies examining relations between DD and PD, however, have typically employed small samples, limiting their power to detect small but significant correlations. Larger samples may help demonstrate such small but significant relations.

Amazon.com's Mechanical Turk (AMT) may be a viable method of quickly collecting discounting data from a large sample. AMT is a crowdsourcing service wherein researchers (i.e., requesters) post tasks for participants (i.e., workers) to complete. Buhrmester, Kwang, and Gosling (2011) reported that AMT's large subject pool expedited rapid recruitment and reliable data collection from a sample that was more diverse than university-based samples. Moreover, Sprouse (2011) directly replicated one of his laboratory experiments via AMT.

The current study used AMT to collect data from a large sample to clarify the relation between DD and PD rates. Because using AMT is relatively new in discounting research, the consistency between the present and previous findings were used to validate AMT.

2 Method

2.1 Participants

Participants completed the study as an AMT Human Intelligence Task (HIT). When using AMT, users work can be evaluated by the HIT's requestor and either accepted or rejected. Only AMT users for whom previous requesters had accepted 90 percent of their previous HITs could access the survey. 1190 individuals from the United States completed the survey. To ensure that participants carefully completed the survey, users' HITs were rejected if they (a) failed to indicate that they understood the instructions, (b) did not complete more than 80% of the survey items, or (c) completed the survey in less than 800 seconds (the mean completion time was 1472 seconds). Additionally, participants' data were excluded from analysis if they reflected non-varying responses (i.e., always choosing one of the two alternatives) on either discounting survey. Analyses included 904 participants' data, which passed all of these screening criteria. (See Table 1 for demographic information.)

2.2 Materials

The data represent a subset of answers to questions in an approximately 200-question survey about health, social behaviors, and decision-making. This survey included demographic questions (e.g., age, gender, income, education, and smoking status) and discounting assessments. The survey included two 21-question monetary choice questionnaires MCQs (Kirby and Marakovic 1996), one assessing rates of DD, the other being a new questionnaire assessing rates of PD. (See Table 2 for a complete list of the discounting questions, and the order in which they appeared.)

2.2.1 Delay discounting monetary choice questionnaire (DD MCQ)—Participants chose between receiving an amount of hypothetical money immediately or at specified delays. For instance, the choice was between "$25 tonight, for you alone" or "$35 in 25 days, for you alone." [1]

2.2.2 Probability discounting monetary choice questionnaire (PD MCQ)—
Participants chose between receiving a smaller, certain amount of hypothetical money or a probabilistic receipt of a larger amount of money. For instance, one item in the questionnaire offered participants a choice between receiving "$25 for sure" or having "a 75% chance of getting $35." Choices for the PD MCQ were constructed by modifying the DD MCQ such that a delay in monetary gain of one day in the DD MCQ corresponded to a 1% decrease in probability of monetary gain in the PD MCQ.

2.3 Procedures

Participants accessed the survey by logging onto AMT and clicking on the "Decision Making Study" HIT. Participants first read an overview of the study and agreed to participate by checking an on-screen box. Monetary compensation was provided for timely and accurate survey completion. Participants received $2.50 for submission of the survey and could receive an additional $2.50 bonus. Respondents did not receive a $2.50 bonus if two or more discounting questions were left unanswered, or they provided an unvarying response pattern on the DD MCQ. The entire evaluation was completed very rapidly (i.e., approximately 24 hours), yet to assuage our concerns regarding the consistent order of the two surveys, we ran a subset of participants with the order to the questionnaires reversed. Thus, 1143 subjects completed the DD MCQ first, whereas 47 subjects completed the PD MCQ first. Although the sample sizes differed between the orders, there was no significant difference between the orders for either discounting measure (ln(*k*): t_{902}= 0.27, p= 0.79; ln(*h*): t_{902}=1.84 df, p=0.07) Furthermore, the observed effect sizes for this comparison were small (Cohen's *d*= 0.04 and 0.30 for ln(*k*) and ln(*H*) respectively). The lack of statistical significance combined with small observed effect sizes indicates that an order effect is implausible, and thus data are presented together.

2.4 Data analysis

For each MCQ, a hyperbolic discounting parameter value was computed using a method modified from Kirby and Marakovic (1996). The 21 questions are organized into 7 ranks of impulsiveness (see Table 2 for details). Discounting rates were estimated by determining which of the discounting rates from the table was most plausible given the pattern of responding (see Kirby, Petry, and Bickel 1999, for details). Ties between equally plausible parameter values were resolved by taking the geometric mean of the plausible values. This value was used in subsequent analysis of delay (*k*) and probability (*h*) discounting rates. It has been noted in the literature that raw *k* and *h* values are generally unsuitable for parametric analysis because they tend to arise from skewed distributions. Logging these values tends to impart symmetry which is more appropriate for parametric statistical analysis. The unlogged values in the current investigation exhibited high levels of skewedness (k= 3.01; h = 1.36), whereas the logged values did not (ln[k] = −0.28; ln[h]= −0.25). Further analysis of the data were therefore conducted on the logged discounting

[1]The data presented were part of a larger survey. The delay discounting questions asked about reinforcers for the participant alone because the delay discounting questionnaire was also used to assess the impact of individual versus group reinforcers (Bickel et al., in press). No such individual versus group comparison was made for probability discounting. It is unknown if this frame impacted responding.

rates. Additionally, because the PD survey was novel to this evaluation Cronbach's alphas were computed to determine the reliability of each discounting questionnaire.

3 Results

The ln(*k*) (M = −4.23; SD =1.12) and ln(*h*) (M= 0.85; SD =0.70) distributions had very little overlap. Histograms of both distributions were inspected, revealing symmetric bell-shaped distributions appropriate for parametric analysis. Discounting rates were correlated with each other (r=0.165) and some demographic variables (Table 1). Cronbach alphas were good-to-acceptable for both of the discounting questionnaires (DD: α=0.89; PD: α=0.72). These coefficients indicate that the probability discounting has acceptable reliability and the delay discounting questionnaire has good reliability according to the rule of thumb in Kline (1999). [Note: One of the 21 questions in the probability questionnaire was omitted in the computation of Cronbach's alpha because all respondents answered identically.]Moreover, consistent with previous reports (Bickel, Odum, and Madden 1999; Bickel et al. 2008; Mitchell 1999; Reynolds et al. 2003), DD rates were significantly higher in smokers (mean ln(*k*)=−3.90; n=200) than non-smokers (mean ln(*k*)= −4.32; n =703; t_{901}= 4.73; p<0.0001); whereas PD rates were not significantly different for smokers (mean ln(*h*)=0.85) and non-smokers (mean ln(*h*)=0.84; t_{901}=0.20; p=0.42) (Reynolds et al. 2004; Yi, Chase, and Bickel 2007). A principal component analysis (PCA) was conducted to examine the covariance structure of ln(*k*) and ln(*h*). Findings of the PCA suggested that both ln(*k*) and ln(*h*) loaded on each of two-factors, with 58% of the variance accounted for by the first factor (Eigenvalue = 1.16), and 42% accounted for by the second factor (Eigenvalue =0.84).

4 Discussion

The present study's large sample provided the power needed to demonstrate whether a significant relation exists between DD and PD. The correlation between ln(*k*) and ln(*h*), however, was small, and in the opposite direction one would expect if one DD and PD reflected a single construct such as impulsivity (i.e., more rapid DD, possibility interpreted as "impatience", positively correlated with more rapid PD, possibly interpreted as less "risk taking"). Additionally, the PCA found that the variance in ln(*k*) and ln(*h*) relatively evenly spread across a two factor model (i.e., did not load on a single factor). Moreover, DD rates were significantly related to smoking status, whereas PD rates were not. These findings suggest that although delay and probability discounting may be related, these constructs are not likely manifestations of a common construct such as impulsivity (Holt, Green, and Myerson 2003; Myerson et al., 2003). Because a large sample was needed to demonstrate this relation, however, it is not surprising that smaller scale studies (Mitchell 1999; Richards et al. 1999; Holt, Green, and Myerson 2003; Shead and Hodgins 2009; Madden, Petry, and Johnson 2009; Olsen et al. 2007; Petry 2011; Reynolds et al. 2004) have provided conflicting results.

The collection of this large sample was facilitated by the use of the AMT platform (also see, Bickel et al. in press). The current findings suggest that AMT may be suitable for collecting PD and DD data. The discounting rates (i.e., ln[*k*] and ln[*h*]) collected using AMT were consistent with those collected in previous discounting studies, suggesting that participants in AMT respond much like they do in the laboratory. Moreover, a number of relations demonstrated with laboratory techniques were replicated in the present demonstration of AMT. For example, ln(*k*)s from the present project were correlated with age (Green, Fry, and Myerson 1994; Green et al. 1996), income (Green et al. 1996), and level of educational achievement (Jaroni et al. 2004) and, were higher in smokers than non-smokers (Bickel and Madden 1999; Bickel, Odum, and Madden 1999; Mitchell 1999).

The rapidity and relatively low cost of collecting discounting data via AMT may facilitate large scale of investigation of the role of DD and PD on everyday decision making. Such large-scale investigations may help demonstrate the relation between delay discounting and a wide range of health related behaviors. For example, by calculating DD rates from data collected as part of the Health Retirement Study (NIA, 2007; n= 987), Bradford (2010) found that DD rates are negatively correlated with the likelihood of participants engaging in pro-health behavior (i.e., having mammograms, dental visits, cholesterol testing, flu shots, and exercising).

The PD MCQ developed for the current study was a straightforward translation of the DD MCQ (Kirby and Marakovic 1996; Kirby, Petry, and Bickel 1999), which used the same number of questions and reinforcer magnitudes, enabling comparisons across DD and PD questionnaires. This version of the PD MCQ yielded data that are generally consistent with previous PD studies. For example, rates of PD were higher than rates of DD (e.g., Andrade and Petry 2012), suggesting that the current PD MCQ may be a viable way to rapidly collect PD data.

The current study, however, had limitations that future research should address. First, although the PD MCQ mapped onto the magnitudes and pattern of changes from the DD MCQ the exact order of the ranks differed from instrument to instrument (see Table 2). The current findings suggest that the PD MCQ sampled a sufficient range of choices, but the sufficiency of the measure should be further validated. Second, the questions were framed slightly differently across the questionnaires (i.e., the delay discounting questionnaire specified “tonight” and “for you alone”), future studies could investigate if those frames appreciably impacted responding. Third, although our results were consistent with previous findings, participants may not have responded thoughtfully during this internet-based survey. The bonus system we used was intended to minimize this risk, but this is an issue that will require constant attention as future research uses the AMT platform. This risk may have been born out in approximately 20% of the subjects’ data being excluded from analysis (see participants section of details). This percentage, however, is comparable to the rate of data excluded in previous studies using AMT (Buhrmester et al., 2011; Sprouse, 2011) or the MCQ (Kirby, Petry, and Bickel 1999; Kirby and Marakovic 1996).

Despite these limitations, AMT and the modified PD MCQ may be viable ways to collect discounting data. If so, these tools may facilitate the collection and analysis of the large datasets needed to examine the influence of discounting differences in non-clinical samples, further demonstrating the generality of these laboratory derived principles.

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Highlights

- A small but significant relation was observed between delay and probability discounting.
- Delay and probability discounting do not appear to be manifestations of the same process.
- Results using the online Amazon Mechanical Turk platform we consistent with those from the laboratory.

Table 1

Spearman correlations between demographic variables and discounting measures

Correlations

	Gender (% female)	Age (years)	Education	Income (US $)	DD (ln[k])	PD (ln[h])
DD	0.028	−0.121**	−0.199***	−0.110**		
PD	0.143***	0.051	−0.083*	0.046	0.165***	

Medians and Interquartile ranges (IQR)

	Gender (% female)	Age (years)	Education	Income (US $)	DD (ln[k])	PD (ln[h])
Median	51.77	28	<HS: 1.9%	23749	−4.171	0.771
IQR	----	21,35	HS: 10.2% SC: 34.6% AA: 7.8% BA: 31.5% >BA:14.1%	6999, 46249	−4.902, −3.439	1.282, 0.259

* p<0.05;

** p<0.01;

*** p<0.0001

Table 2

Questions, order, ranks, and associated *k*/*h* values for monetary discounting tasks.

	Delay Discounting Survey			Probability Discounting Survey		
Order	**Choice Presented**	***k***	**Rank**	**Choice Presented**	***h***	**Rank**
4	$34 tonight, for you alone, or	0.0007	1	$34 for sure, or a	0.0390	1
	$35 in 43 days, for you alone			57% chance of getting $35		
15	$53 tonight, for you alone, or	0.0007	1	$53 for sure, or a	0.0309	1
	$55 in 55 days, for you alone			45% chance of getting $55		
7	$83 tonight, for you alone, or	0.0007	1	$83 for sure, or a	0.0448	1
	$85 in 35 days, for you alone			65% chance of getting $85		
20	$27 tonight, for you alone, or	0.0032	2	$27 for sure, or a	0.2063	3
	$30 in 35 days, for you alone			65% chance of getting $30		
9	$48 tonight, for you alone, or	0.0032	2	$48 for sure, or a	0.1782	2
	$55 in 45 days, for you alone			55% chance of getting $55		
12	$65 tonight, for you alone, or	0.0031	2	$65 for sure, or a	0.1538	2
	$75 in 50 days, for you alone			50% chance of getting $75		
8	$21 tonight, for you alone, or	0.0057	3	$21 for sure, or a	0.1429	2
	$30 in 75 days, for you alone			25% chance of getting $30		
16	$47 tonight, for you alone, or	0.0055	3	$47 for sure, or a	0.0426	1
	$50 in 60 days, for you alone			40% chance of getting $50		
14	$30 tonight, for you alone, or	0.0083	4	$30 for sure, or an	0.6667	4
	$35 in 20 days, for you alone			80% chance of getting $35		
10	$40 tonight, for you alone, or	0.0089	4	$40 for sure, or a	0.2679	3
	$65 in 70 days, for you alone			30% chance of getting $65		
3	$67 tonight, for you alone, or	0.0077	4	$67 for sure, or a	0.4989	4
	$85 in 35 days, for you alone			65% chance of getting $85		
18	$50 tonight, for you alone, or	0.0086	4	$50 for sure, or a	0.2571	3
	$80 in 70 days, for you alone			30% chance of getting $80		
11	$25 tonight, for you alone, or	0.0160	5	$25 for sure, or a	1.2000	5
	$35 in 25 days, for you alone			75% chance of getting $35		
2	$40 tonight, for you alone, or	0.0150	5	$40 for sure, or a	1.1250	5

	Delay Discounting Survey			Probability Discounting Survey		
Order	**Choice Presented**	***k***	**Rank**	**Choice Presented**	***h***	**Rank**
	$55 in 25 days, for you alone			75% chance of getting $55		
19	$45 tonight, for you alone, or	0.0159	5	$45 for sure, or a	1.0317	5
	$70 in 35 days, for you alone			65% chance of getting $70		
21	$16 tonight, for you alone, or	0.0250	6	$16 for sure, or a	1.6250	5
	$30 in 35 days, for you alone			65% chance of getting $30		
6	$32 tonight, for you alone, or	0.0359	6	$32 for sure, or a	2.8750	6
	$55 in 20 days, for you alone			80% chance of getting $55		
17	$40 tonight, for you alone, or	0.0375	6	$40 for sure, or a	3.0000	6
	$70 in 20 days, for you alone			80% chance of getting $70		
5	$15 tonight, for you alone, or	0.1333	7	$15 for sure, or a	12.000	7
	$35 in 10 days, for you alone			90% chance of getting $35		
13	$24 tonight, for you alone, or	0.1292	7	$24 for sure, or a	5.1667	6
	$55 in 10 days, for you alone			90% chance of getting $55		
1	$30 tonight, for you alone, or	0.1310	7	$30 for sure, or an	11.262	7
	$85 in 14 days, for you alone			86% chance of getting $85		