OXFORD
UNIVERSITY PRESS

Archives of Clinical Neuropsychology 29 (2014) 651–662

Archives of CLINICAL NEUROPSYCHOLOGY

Delay and Probability Discounting as Candidate Markers for Dementia: An Initial Investigation

Cutter A. Lindbergh[a,*], Antonio N. Puente[a], Joshua C. Gray[a], James Mackillop[a], L. Stephen Miller[a,b]

[a]*Department of Psychology, University of Georgia, Athens, GA 30602, USA*
[b]*Bio-Imaging Research Center, Paul D. Coverdell Center, University of Georgia, Athens, GA 30602, USA*

*Corresponding author at: Department of Psychology, University of Georgia, Athens, GA 30602, USA. Tel.: 1-406-493-7072; fax: 1-706-542-8048.
E-mail address: cal@uga.edu.

Accepted 1 August 2014

Abstract

The present study investigated delay discounting and probability discounting—behavioral economic indices of impulsivity and risk proneness, respectively—in 39 healthy older adults and 25 older adults with mild cognitive impairment (MCI). Relative to the healthy group, it was hypothesized that older adults with MCI would display greater levels of impulsivity, risk proneness, and response inconsistency. The MCI group was found to display a unique delay discounting profile characterized by increasing impulsivity with decreasing reward magnitude, such that cognitively impaired older adults were significantly more impulsive than healthy controls at the small reward magnitude. The two groups exhibited similar levels of probability discounting, though older adults with MCI were significantly less consistent in their risk preferences. The present findings shed light onto decision-making in pre-dementia disease stages and suggest that discounting performance holds potential to complement early diagnostic instruments, likely due to pathophysiological processes in relevant brain regions.

Keywords: Aging; Behavioral economics; Cognition; Delay discounting; Mild cognitive impairment; Probability discounting

Introduction

Alzheimer's disease (AD)—the primary cause of neurodegenerative dementia—is a worldwide health crisis based on prevalence, death toll, and economic burden to society (Alzheimer's Association, 2013; Hurd, Martorell, Delavande, Mullen, & Langa, 2013). A major obstacle to the development of successful treatments is that disease processes commence decades prior to the onset of readily observable symptoms (Morris, 2005; Weiner et al., 2012). Given that interventions will likely be incapable of undoing neuronal damage and loss, reliable early detection strategies are of critical importance (Borson et al., 2013; Rapoport, 2003).

The present study turned to the field of behavioral economics for a novel approach to the investigation of potential early detection strategies. Behavioral economics is a hybrid of psychology and microeconomics that is primarily concerned with decision-making and behavior within systems of constraint (Bickel, Marsch, & Carroll, 2000). Two hallmark behavioral economic measures are delay discounting and probability discounting. Delay discounting evaluates preferences between smaller, immediate and larger, delayed rewards (e.g., "Would you rather have $34.00 today or $50.00 in 30 days?") to provide an index of impulsivity that reflects the degree to which an individual devalues a reward according to the temporal distance of its receipt (Kirby, Petry, & Bickel, 1999; Rachlin, Raineri, & Cross, 1991). In contrast, probability discounting evaluates preferences between smaller, guaranteed and larger, probabilistic rewards (e.g., "Would you rather have $30.00 guaranteed or a 50% chance of receiving $100.00?") to provide an index of risk taking that reflects the degree to which an individual devalues a reward according to the probability of its receipt (Rachlin et al., 1991).

To date, no study has evaluated discounting performance in pathologically aging older adults. A small number of studies have investigated delay discounting in healthy older adults (Green, Fry, & Myerson, 1994; Green, Myerson, Lichtman, Rosen, & Fry, 1996; Harrison, Lau, & Williams, 2002; Read & Read, 2004; Roalf, Mitchell, Harbaugh, & Janowsky, 2011), which generally

doi:10.1093/arclin/acu043 Advance Access publication on 18 September 2014

seems to remain unaltered from young adulthood to normal old age when controlling for socioeconomic status (Green et al., 1996; Roalf et al., 2011). Among both healthy older adults and pathologically aging older adults, probability discounting has remained largely unexplored.

There are several reasons to suggest that pathological aging due to AD would lead to altered delay discounting performance. First, AD is associated with the emergence of impulsive behaviors, and this appears to occur even in early disease stages (Holmes, Johnson, & Roedel, 1993; Rochat et al., 2013). Second, it is well established that general impairments in decision-making are associated with neurodegenerative conditions, including various forms of dementia (Brand et al., 2005; Cools, Barker, Sahakian, & Robbins, 2003; Delazer, Sinz, Zamarian, & Benke, 2007; Stout, Rodawalt, & Siemers, 2001; Torralva et al., 2007). Together, the impulsivity changes and decision-making deficits associated with neurodegenerative processes may synergistically interact to influence delay discounting performance (Zermatten, Van der Linden, d'Acremont, Jermann, & Bechara, 2005).

Third, delay discounting utilizes several cognitive abilities that deteriorate with the progression of dementia, most notably executive functions (EFs; Belleville, Chertkow, & Gauthier, 2007; Belleville, Rouleau, & Van der Linden, 2006; Lambon, Patterson, Graham, Dawson, & Hodges, 2003; Logie, Cocchini, Della Sala, & Baddeley, 2004; Stopford, Thompson, Neary, Richardson, & Snowden, 2012). Executive dysfunction is among the earliest symptoms of AD, often preceding decline in other cognitive domains (Albert, Moss, Tanzi, & Jones, 2001; Baudic et al., 2006; Bondi et al., 2002; Brandt et al., 2009; Busse, Hensel, Guhne, Angermeyer, & Riedel-Heller, 2006; Chen et al., 2009; Perry, Watson, & Hodges, 2000; Twamley, Ropacki, & Bondi, 2006). Higher levels of delay discounting have consistently been associated with executive dysfunction (e.g., Hinson, Jameson, & Whitney, 2003; Huckans et al., 2011; Olson, Hooper, Collins, & Luciana, 2007), particularly within the domain of working memory (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Bickel, Yi, Landes, Hill, & Baxter, 2011; Bobova, Finn, Rickert, & Lucas, 2009; Hinson et al., 2003; Petry, 2002; Shamosh et al., 2008).

Greater delay discounting is related to worse performance on other neuropsychological variables as well, including verbal learning, attention, and delayed memory (Hoffman et al., 2006; Huckans et al., 2011). AD patients consistently show impairments in these domains, which often emerge at preclinical stages (e.g., Fox, Olin, Erblich, Ippen, & Schneider, 1998; Genon et al., 2013; Moulin, James, Freeman, & Jones, 2004; Petersen, Smith, Ivnik, Kokmen, & Tangalos, 1994; Saunders & Summers, 2010). It should be noted that poor delayed memory performance is also correlated with delay discounting response inconsistency (Avsar et al., 2013).

As mentioned above, no studies have evaluated probability discounting in healthy or pathologically aging older adults. The available literature on risk-based decision-making more generally paints a nuanced portrait of age-related changes in risk preference that depends on task and context (e.g., Denberg, Bechara, Tranel, Hindes, & Damasio, 1999; Denburg, Tranel, & Bechara, 2005; Dror, Katona, & Mungur, 1998; Kovalchik, Camerer, Grether, Plott, & Allman, 2005; Kumar, 2009; Mather, 2006; Roalf et al., 2011). More recently, it was demonstrated that age-related changes in decision quality and risk preferences are mediated by changes in cognitive abilities, specifically processing speed and memory (Henninger, Madden, & Huettel, 2010). Importantly, deficits in each of these domains emerge in pre-symptomatic dementia stages, suggesting that altered risk-based decision-making may be present early in the disease course and serve as a marker for underlying pathobiological processes (Wadley, Okonkwo, Crowe, Ross-& Meadows, 2008). The predictive utility of risky decision-making is supported by longitudinal findings showing a relationship between gambling task performance at baseline and cognitive decline at a 5-year follow-up assessment (Denburg et al., 2005).

Only a handful of studies have investigated decision-making under risky conditions in individuals with AD or mild cognitive impairment (MCI)—a pre-dementia syndrome in which sufficient AD pathology accumulates in the brain to result in impairment in one or more cognitive domains, but functional independence is retained (Albert et al., 2011; Petersen et al., 2001). Findings have been consistent with the notion that risky decision-making is altered in early disease stages. More specifically, across a variety of risk-based tasks, older adults with AD or MCI were more inconsistent in their selections and had a smaller proportion of "consistently safe" (i.e., risk averse) respondents relative to healthy controls (Delazer et al., 2007; Sinz, Zamarian, Benke, Wenning, & Delazer, 2008; Zamarian, Weiss, & Delazer, 2011).

In summary, there is considerable evidence to suggest that delay and probability discounting may be altered early on in the course of AD. Based on this, the present study is an initial investigation to evaluate the potential of discounting performance to serve as a preclinical diagnostic instrument by comparing the performance of older adults with MCI to healthy controls. Relative to controls, the MCI group was hypothesized to display more impulsive delay discounting, as evidenced by greater hyperbolic discounting functions, k (Mazur, 1987). It was further predicted that individuals with MCI would demonstrate more risky probability discounting, as evidenced by greater area-under-the-curve (AUC) values. A final hypothesis was that less consistent discounting preferences would be observed in the MCI group, as assessed by selections that were incongruent with estimated levels of impulsivity/risk proneness across different delays/odds against.

Method

Participants

Thirty-five cognitively intact and 25 older adults with MCI from 65 to 85 years of age were recruited from the community via flyers and newspaper advertisements. Exclusionary criteria included a history of neurological illness, self-reported illiteracy, evidence that the individual was demented, and/or severe cognitive impairment as indicated by a score of 20 or less on the Mini-Mental State Examination (MMSE; Folstein, Folstein, McHugh, & Fanjiang, 2000). In addition, participants with a history of substance dependence within the past 5 years were excluded given that it may have confounded discounting performance (e.g., Bickel & Marsch, 2001; Coffey, Gudleski, Saladin, & Brady, 2003; Petry, 2001). One cognitively intact older adult was excluded from analyses due to invalid responding on discounting control trials (incorrect choices in decision for larger vs. smaller rewards, both available immediately). Participants received a small monetary compensation of $20.00 for their time, as well as a gift bag containing University of Georgia souvenirs valued at ∼$15.00. In addition, participants were given a 1 in 6 chance (determined via dice roll) of receiving the cash value of one of their delay discounting choices, which was determined randomly and ranged in value from $10.00 to $100.00 (Kirby & Petry, 2004). The dice roll was included to maximize effort and attention (Kirby & Petry, 2004).

Cognitive Measures

Cognitive status. Participants were diagnosed with MCI based on guidelines recently proposed by the National Institute on Aging-Alzheimer's Association workgroups (Albert et al., 2011), which include concern regarding a change in cognition from previous levels, objective evidence of cognitive impairment in one or more cognitive domains, and continued functional independence in day-to-day life. A semi-structured interview was used to evaluate subjective perceptions of changes in cognitive abilities and preservation of functional abilities. The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph, 1998) and select subtests from The Delis–Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) were employed to provide an objective assessment of cognitive impairment (see below). Consistent with Albert and colleagues (2011) recommendations, cognitive impairment was operationalized as performing at least 1.5 *SD* below the normative sample of healthy, age-matched peers on any of the five indices of the RBANS or subtests of the D-KEFS.

Mini-Mental State Examination. The MMSE was utilized as an initial screening tool to exclude individuals who would have been inappropriate for our study due to severe cognitive impairment (Folstein, Folstein, & McHugh, 1975; Folstein et al., 2000). Examinees can receive scores ranging from 0 to 30 points, with scores of 20 or below nearly always being consistent with the presence of dementia or some major psychological disorder, such as schizophrenia (Folstein et al., 1975). The MMSE is a reliable and valid screening instrument for cognitive impairment (Folstein et al., 1975).

The Wechsler Test of Adult Reading. The Wechsler Test of Adult Reading (WTAR; The Psychological Corporation, 2001) was employed to assess overall premorbid intellectual functioning across participants (Wechsler, 2001). This measure takes roughly 5 min to administer and determines an examinee's ability to correctly pronounce a list of words, as reading recognition has shown considerable stability in the face of cognitive decline (Wechsler, 2001). The WTAR provides full scale intelligence quotient (FSIQ) estimates using an algorithm based on WTAR performance and demographic (i.e., age, education, race, sex, and geographic region) variables.

Repeatable Battery for the Assessment of Neuropsychological Status. The RBANS was included to provide an objective assessment of cognitive impairment when diagnosing participants with MCI. Cognitive impairment was operationalized as performing at least 1.5 *SD* below the normative sample on one or more of the five Index Scores (Visuospatial/Constructional, Attention, Language, Immediate Memory, and Delayed Memory), which are derived from 12 subtests (Figure Copy, Line Orientation, Digit Span, Coding, Picture Naming, Semantic Fluency, List Learning, Story Memory, List Recall, List Recognition, Story Recall, and Figure Recall; Randolph, 1998). This battery takes roughly 30 min to administer and has norms available for individuals up to 89 years of age.

Delis–Kaplan Executive Function System. Select subtests of the D-KEFS were administered to supplement the RBANS in the assessment of MCI based on the importance of executive deficits to this condition (Albert et al., 2011; Chen et al., 2009; Twamley et al., 2006). The DKEFS is a battery of nine subtests adapted from several traditional neuropsychological measures designed to measure various aspects of EF (Delis et al., 2001). Trail Making Test (TMT) and Tower Test were utilized in light

of demonstrated sensitivity and specificity to MCI (Ashendorf et al., 2008; Fernández-Ballesteros, Zamarrón, & Tàrraga, 2005). Cognitive impairment was operationalized as a completion-time score on TMT condition 4 (number-letter switching) and/or a total achievement score on Tower Test of at least 1.5 *SD* below the normative sample.

Behavioral Economic Measures

The discounting tasks, elaborated below, were used to derive the primary dependent variables of interest: delay discounting impulsivity, delay discounting response consistency, probability discounting risk proneness, and probability discounting response consistency.

Delay discounting. Two delay discounting tasks were employed, which collectively allowed for discounting performance to be assessed at a range of reward magnitudes. This was deemed important given that discounting rates have been shown to vary depending on the monetary value of the delayed reward (e.g., Kirby, 1997). The Monetary Choice Questionnaire (MCQ) comprises 27 dichotomous choices between smaller, immediate monetary values and larger, delayed monetary values (e.g., "Would you rather have $54.00 today or $80.00 in 30 days?"; Kirby et al., 1999). The 27 choice trials are varied such that estimates of impulsivity and response consistency can be calculated for three magnitudes of the larger, delayed reward: small ($25–35), medium ($50–60), and large ($75–85). Delay discounting was also assessed using an 80-item delay discounting task (80-DDT) comprised of dichotomous choices between smaller, immediate rewards (i.e., $10.00, $20.00, $30.00, $40.00, $50.00, $60.00, $70.00, $80.00, $90.00, or $99.00) and a larger, delayed reward that was fixed at $100 with a delay of 1, 7, 14, 30, 60, 90, 180, or 365 days (Amlung, Sweet, Acker, Brown, & MacKillop, 2013). The 80-DDT could thus be said to provide an estimate of impulsivity and response consistency at an "extra-large" reward magnitude (i.e., $100) relative to the MCQ. For the present study, computer-adapted versions of the delay discounting tasks were programmed using Inquisit software (Inquisit, 2011) and participants were instructed to indicate their personal preference on each trial by mouse click. To verify sufficient effort and valid performance, 10 control trials were included that consisted of dichotomous choices between smaller and larger monetary values both available as immediate rewards. Several studies have provided evidence for the internal consistency, intertemporal reliability, and validity of delay discounting tasks, and importantly these psychometric properties do not appear to be population or culture specific (e.g., Black & Rosen, 2011; Duckworth & Seligman, 2005; Kirby et al., 1999, 2002; Kirby & Petry, 2004; Kirby, Winston, & Santiesteban, 2005; Odum, Madden, Badger, & Bickel, 2000; Ohmura, Takahashi, Kitamura, & Wehr, 2006; Simpson & Vuchinich, 2000; Vuchinich & Simpson, 1998).

Probability discounting. The probability discounting paradigm (Rachlin et al., 1991) comprised 66 dichotomous choices between smaller, guaranteed monetary values and a larger, probabilistic monetary value (e.g., "Would you rather have $60.00 guaranteed or a 50% chance of receiving $100.00?"). The smaller, guaranteed rewards ranged in value from $1.00 to $99.00 (i.e., $1.00, $10.00, $20.00, $30.00, $40.00, $50.00, $60.00, $70.00, $80.00, $90.00, or $99.00), while the larger reward was set at $100.00 with a probability of receipt of 0.01, 0.10, 0.25, 0.50, 0.75, or 0.99. Accordingly, the task allows for the determination of an indifference point at each of the six probability intervals. The indifference points represent the subjective value of the larger reward for a given probability of receipt—in other words, the value at which a respondent is "indifferent" as to whether he/she would select the guaranteed or the probabilistic reward. Similar to the presentation of the MCQ described above, participants completed a computerized version of the task that was programmed using Inquisit software (Inquisit, 2011) and were instructed to indicate their personal preference on each trial by mouse click. Probability discounting has been demonstrated as a reliable (e.g., Ohmura et al., 2006; Richards, Zhang, Mitchell, & de Wit, 1999) and valid (e.g., Holt, Green, & Myerson, 2003; Madden, Petry, & Johnson, 2009; Petry, 2012; Reynolds, Richards, Horn, & Karraker, 2004) measure of risk proneness.

Procedure

Each participant was tested in a single session that commenced with written informed consent. After consent was obtained, the MMSE was administered to screen out individuals with cognitive deficits that may have prevented the comprehension of experimental tasks and/or compromised the validity of self-report measures. Key demographic information was collected next, such as age, presence of neurological illness, and history of substance dependence. If inclusion criteria were met thus far, a semi-structured interview was administered to assess subjective perceptions of changes in cognitive functioning and functional independence.

The order of administration of the remaining measures (WTAR, RBANS, D-KEFS, and discounting tasks) was counterbalanced to control for potential order effects. It should be noted that participants also completed a handful of cognitive and functional tasks as part of a larger study, which were unrelated to the present study and thus not a focus of the present analyses. Upon completion of the testing session, participants were fully debriefed, thanked, and compensated for their participation. The study

received ethical approval from the University's Institutional Review Board and research staff consisted of doctoral-level clinical psychology graduate students, who were well trained on interview procedures and assessment administration according to standardized protocols and supervised by a licensed clinical psychologist.

Data Analysis

All variables were evaluated for outliers using a *Z*-score threshold of ± 3.29 to prevent any single case from exerting excessive leverage on the data (Tabachnick & Fidell, 2004). Consistent with procedures utilized in previous studies involving discounting paradigms (e.g., Acker, Amlung, Stojek, Murphy, & MacKillop, 2012; MacKillop et al., 2010), an iterative process was employed in which outlying cases were replaced with values one unit above/below the next highest/lowest non-outlying case (Tabachnick & Fidell, 2004). Application of this procedure resulted in the identification of one outlier on the 80-DDT and two outliers on the probability discounting task. Hyperbolic discounting functions, *k*, were estimated for each participant based on his/her overall pattern of responses using the methods described in detail by Kirby and colleagues (1999). Briefly, *k* is calculated from the function: $V = A/(1 + kD)$, where *V* is the estimated present value of the reward, *A*, after a delay of *D* days (Mazur, 1987). *k* can thus be conceptualized as an "impulsiveness parameter," with larger *k* values indicating higher levels of impulsivity and smaller *k* values indicating lower levels of impulsivity (Kirby et al., 1999). The methods outlined by Kirby and colleagues (1999) were applied to the MCQ to infer *k* at small ($25–$35), medium ($50–$60), and large ($75–$85) reward magnitudes. Nonlinear regression was used to calculate *k* at the extra-large ($100) reward magnitude on the 80-DDT. Response consistency on both the MCQ and the 80-DDT was also quantified using Kirby and colleagues (1999) methods (Amlung et al., 2013). Briefly, consistency is based on the percentage of contradictory responses within each reward magnitude on the MCQ and within each delay interval on the 80-DDT. An overall measure of 80-DDT response consistency was calculated by averaging consistency values across the various delay intervals.

Probability discounting was analyzed using AUC, which is a frequently employed index of probability discounting (e.g., Cinnamon et al., 2013; Dixon, Marley, & Jacobs, 2003; Du, Green, & Myerson, 2002; Ohmura, Takahashi, & Kitamura, 2005; Olson et al., 2007) that avoids assumptions about the form of the data and circumvents potential issues related to model-fit error (Myerson, Green, & Warusawitharana, 2001). Briefly, AUC is calculated by plotting the indifference points, with odds against [= (1/probability of receiving larger reward) − 1] along the horizontal axis and subjective value of the larger reward along the vertical axis, and then summing the area of the underlying trapezoids (for more details, see Myerson et al., 2001). AUC values are then converted into proportionate values (0.00–1.00) with greater values reflecting less discounting of uncertain rewards and thus greater risk taking. Response consistency was calculated by summing the number of instances in which a participant's indifference point increased from one indifference point to the next. This approach was based on the logic that an individual with an internally consistent cognitive template for discounting preferences should display a greater aversion to rewards with an increasingly uncertain probability of receipt (Johnson & Bickel, 2008). To the extent that a respondent fails to do so indicates inconsistent selections across different odds against (e.g., choosing a 50% chance at $100 over a guaranteed $30 on one trial and a guaranteed $30 over a 75% chance at $100 on another trial).

To evaluate whether the healthy and MCI groups differed with respect to delay discounting performance, 2×4 mixed analyses of covariance (ANCOVA) were conducted with cognitive status (i.e., healthy and MCI) as the between-subjects factor and reward magnitude (i.e., small, medium, large, and extra-large) as the within-subject factor. Group differences in probability discounting performance were evaluated using one-way between-subject ANCOVAs.

As indicated in Table 1, individuals with MCI differed significantly from healthy controls on several noteworthy characteristics. The MCI group comprised a higher proportion of females and African Americans than the healthy group, and tended to be

Table 1. Group characteristics

Demographic variable	Controls [% or M (*SD*)]	MCI [% or M (*SD*)]	*p*-value (χ^2 or *t*-test)
Sex (% female)	66.70%	92%	.02*
Race (% African American)	2.60%	24%	.007**
Age (years)	74.70 (5.97)	78.60 (5.22)	.01*
Peak household income (USD)	$103,321 (83,950)	$62,004 (56,291)	.034*
FSIQ (WTAR and demographics predicted)	111 (9.94)	101 (12.36)	.001**
Education (years)	16.44 (2.61)	14.16 (2.79)	.002**

Notes: $*p < .05$. $**p < .01$.
USD = United States Dollars; FSIQ = Full Scale Intelligence Quotient; WTAR = Wechsler Test of Adult Reading; Education = total years of formal education attained.

older with lower peak household incomes, educational attainment, and predicted FSIQs. Income, education, and FSIQ were related to some of our discounting variables of interest and thus were controlled for in our analyses accordingly. Gender and age were not included in the models as covariates as they were unrelated to all of our discounting variables. We elected not to statistically adjust for race given the small number of African Americans in our sample ($n = 7$), which would have resulted in uneven and unstable cells, though note that the results reported below remain virtually identical with African Americans excluded from the data.

Results

As expected, individuals with MCI performed significantly worse than healthy controls on the majority of neuropsychological tests (see Table 2).

Delay Discounting

Our participants appeared to understand the task and put forth adequate effort, as evidenced by the high average percentage of valid responses (97%). Visual inspection of distribution histograms revealed that MCQ and 80-DDT *k* indices were adequately distributed and thus the data were not logarithmically transformed.

FSIQs and educational attainment correlated negatively and significantly with *k* values at all magnitudes of reward, and thus were controlled for in the 2 × 4 mixed design ANCOVA described above. The model revealed a main effect for reward magnitude [Wilks' lambda (λ) = 0.767, $F(3, 58) = 5.889$, $p = .001$, partial $\eta^2 = 0.233$] and a significant interaction [$\lambda = 0.691$, $F(3, 58) = 8.652$, $p = .000078$, partial $\eta^2 = 0.309$], but no main effect for cognitive status ($p = .348$). The estimated marginal means of *k* values adjusted for the covariates are presented graphically in Fig. 1. To explore the interaction, we conservatively elected to use Bonferroni corrected *post hoc* tests for the within-subjects factor, which indicated that the MCI group displayed significantly higher levels of impulsivity as reward magnitudes decreased ($p < .05$), with the exception of a lack of difference between large and medium reward magnitudes ($p = .963$). In contrast, the healthy group displayed similar levels of impulsivity across all reward magnitudes ($p > .99$). Simple effects analyses for the between-subjects factor demonstrated that the MCI group was significantly more impulsive than the healthy group at the small reward magnitude [$F(1, 60) = 6.222$, $p = .015$, partial $\eta^2 = 0.094$], but not at the medium, large, or extra-large reward magnitudes ($p > .05$). It should be noted that African Americans displayed significantly more impulsive discounting than Caucasians across all award magnitudes ($p < .05$).

A 2 × 4 mixed design ANCOVA was again conducted to evaluate group differences in delay discounting response consistency. Educational attainment and income, which correlated positively and significantly with response consistency, were included as covariates in the model. Neither a main effect for cognitive status [$F(1, 60) = 3.143$, $p = .081$] nor a significant interaction [$\lambda = 0.959$, $F(3, 58) = 0.822$, $p = .487$] were observed. Of note, African Americans were more inconsistent in their responses than Caucasians at the extra-large reward magnitude [$t(62) = 2.341$, $p = .022$].

Probability Discounting

AUC values correlated negatively and significantly with predicted FSIQs. Upon controlling for intellectual functioning, ANCOVA revealed that healthy and impaired older adults displayed similar levels of risk proneness ($p = .995$).

Table 2. Neuropsychological performance

Cognitive variable	Controls [% or M (*SD*)]	MCI [% or M (*SD*)]	*p*-value (χ^2 or *t*-test)
RBANS			
Immediate memory	98.18 (14.71)	84.68 (21.33)	.004**
Visuospatial	101.44 (16.91)	88.40 (14.86)	.002**
Language	98.51 (11.04)	93.88 (13.65)	.141
Attention	104.51 (16.89)	89.52 (14.67)	.001**
Delayed memory	103.26 (10.85)	79.96 (21.75)	<.001***
Total score	101.59 (13.21)	83.08 (12.74)	<.001***
D-KEFS			
TMT-4	10.2564 (2.96)	5.0000 (4.15)	<.001***
Tower Test	10.8205 (2.63)	7.6000 (3.19)	<.001***

Notes: **$p < .01$. ***$p < .001$.

RBANS = Repeatable Battery for The Assessment of Neuropsychological Status; D-KEFS = Delis–Kaplan Executive Function System; TMT-4 = Trail Making Test, condition 4.

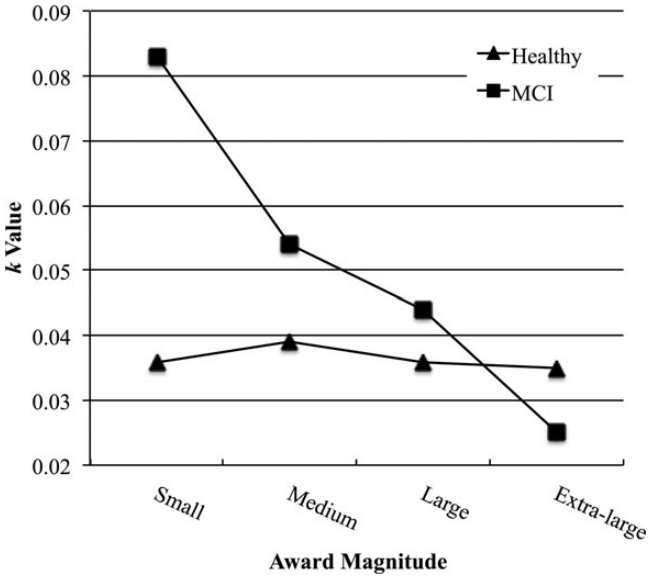

Fig. 1. Delay discounting *k* values by group and reward magnitude. The above figure plots estimated marginal means adjusted for educational attainment (i.e., years of formal education) and estimated premorbid intellectual ability. Older adults with MCI displayed significantly higher levels of impulsivity with decreasing reward magnitude, excluding a non-significant difference between large and medium magnitudes. The MCI group was significantly more impulsive than unimpaired older adults at the small reward magnitude with the covariates in the model.

Lower peak household income, educational attainment, and predicted FSIQs all correlated negatively and significantly with probability discounting response consistency across different odds against. With these variables included as covariates in the model, individuals with MCI were significantly less consistent in their responses than controls [$F(1, 59) = 5.016$, $p = .029$, partial $\eta^2 = 0.078$]. More specifically, in MCI participants, the subjective value of the larger, uncertain reward exhibited an inconsistent pattern of decline across increasingly uncertain probabilities of receipt. It should be noted that African Americans were more likely to display this form of response inconsistency than Caucasians [$t(62) = -2.425$, $p = .018$].

Discussion

The aim of the present study was to evaluate whether delay discounting and probability discounting are altered in older adults with MCI. Consistent with our hypotheses, older adults with MCI displayed significantly higher levels of delay discounting; however, this finding was nuanced by an interaction in which MCI was characterized by increasing impulsivity with decreasing reward magnitudes, whereas healthy aging was characterized by similar levels of impulsivity across reward magnitudes. Small reward magnitude trials emerged as the most sensitive marker of MCI. Older adults with MCI were more inconsistent in their responses on the probability discounting task, but contrary to expectation, displayed similar levels of risk proneness to healthy older adults.

According to the competing neural systems model, delay discounting occurs through the competitive interaction of an "impulsive" subcortical neural system and an "executive" cortical neural system (Bechara, 2005; Bickel et al., 2007). The observed impulsivity among older adults with MCI may reflect pathophysiological changes in executive system neural structures, including prefrontal, parietal, and hippocampal regions (e.g., Pennanen et al., 2004; Singh et al., 2006). Importantly, these brain changes commence decades prior to the onset of dementia (Borson et al., 2013; Morris, 2005; Weiner et al., 2012), which suggests that altered discounting may be apparent in pre-MCI disease stages.

Kirby (1997) provides a compelling case for a delay discounting "magnitude effect," demonstrating that smaller rewards are often discounted by a greater amount per unit time than larger rewards. Indeed, magnitude effects have been observed in a number of delay discounting studies (e.g., Amlung & MacKillop, 2011; Benzion, Rapoport, & Yagil, 1989; Estle, Green, Myerson, & Holt, 2006; Raineri & Rachlin, 1993; Thaler, 1981). Based on our results, it seems that older adults with MCI are more affected by this phenomenon than healthy controls.

An important caveat to our findings that MCI is associated with impulsivity, but not risk proneness is that probability discounting was only assessed at an "extra-large" (i.e., $100) reward magnitude. Accordingly, it will be important to evaluate probabilistic reward discounting in MCI across a broader range of reward magnitudes. Moreover, we elected to evaluate risk proneness using

AUC rather than h, the probability discounting hyperbolic analog of k (Rachlin et al., 1991), as the literature suggests that AUC may have certain advantages over h. However, we acknowledge that our analytic strategy renders direct comparisons between the delay and probability discounting tasks difficult. To increase the interpretability of our results, we conducted parallel analyses of our data using h. In support of our findings, these analyses similarly revealed a lack of a group difference in risk proneness ($p = .533$).

Our results provide preliminary support for the potential of decision-making performance under conditions of impulsivity and risk to assist in the assessment of pre-dementia disease stages. The effect sizes that we observed where significant group differences emerged generally fell within the moderate to large range (Cohen, 1988), even after including relevant covariates in the model. Interestingly, a very large effect (partial $\eta^2 = 0.309$) was observed for the cognitive status × reward magnitude interaction term (Cohen, 1988), which suggests that the most robust early marker may be discrepancies in impulsivity levels across different magnitudes of reward.

Despite the respectable magnitudes of these effects, it is unlikely that discounting performance could serve as a standalone diagnostic tool. Currently, the most successful classification approaches combine features from multiple modalities (e.g., cerebrospinal fluid biomarkers, MRI, [^{18}F]-fluorodeoxyglucose positron emission tomography, age, or apolipoprotein E ε4 allele status) into optimally weighed algorithms (Weiner et al., 2012). While such approaches are able to attain accuracies of over 90% in discriminating between AD patients and healthy controls (e.g., Ewers et al., 2012), they are much worse in identifying individuals in preclinical disease stages (Kohannim et al., 2010). It is feasible that patterns of impulsive and risky decision-making could be incorporated into algorithms to improve accuracies, potentially evaluating unique aspects of the condition not assessed by other modalities.

Prior to implementation in clinical settings, however, it will be necessary to establish that discounting performance predicts MCI status above and beyond relevant aspects of cognition, perhaps most notably executive dysfunction. Additionally, although discounting has been studied extensively in various conditions associated with self-control impairments (e.g., Barkley et al., 2001; Bickel, Odum, & Madden, 1999; Coffey et al., 2003; Holt et al., 2003; MacKillop, Anderson, Castelda, Mattson, & Donovick, 2006; Petry, 2001; Petry, 2002; Reynolds et al., 2004), the establishment of normative data and psychometric properties in healthy and pathologically aging older adults is necessary prior to the application of these tasks in the clinical arena. Along these lines, MCI is a syndrome characterized by a diverse presentation of cognitive impairments (e.g., Petersen et al., 2009). Although the MCI group in the present study displayed considerable heterogeneity in clinical phenotype—including amnestic single domain ($n = 2$), amnestic multiple domain ($n = 11$), non-amnestic single domain ($n = 7$), and non-amnestic multiple domain ($n = 5$)—it was markedly dysexecutive ($n = 20$) with a limited representation of language deficits ($n = 2$), though the latter observation may reflect an insensitivity of the RBANS Language Index to subtle deficit (e.g., Duff et al., 2008; McKay, Casey, Wertheimer, & Fichtenberg, 2007). In any case, an important future avenue for research will be to determine whether discounting performance varies with clinical phenotype. Unfortunately, the present study does little to contribute to such endeavors given limitations in sample size.

Beyond the realm of early detection, the finding that MCI is associated with increased impulsivity and response inconsistency has practical implications. As examples, impulsive delay discounting predicts substance abuse, gambling, and various health and safety choices, such as whether to eat breakfast, apply sunscreen, maintain a healthy body weight, and wear a seatbelt (Alessi & Petry, 2003; Daugherty & Brase, 2010; Kollins, 2003; Reimers, Maylor, Stewart, & Chater, 2009), as well as financial decisions, such as retirement age (Bidewell, Griffin, & Hesketh, 2006). In addition, inconsistencies in decision-making—specifically in the context of risky scenarios—have been associated with poor financial outcomes (Jacobson & Petrie, 2009; Prasad & Salmon, 2013).

There were limitations of the present study that warrant mention, most notably that our healthy and cognitively impaired groups significantly differed with respect to several important characteristics. Part of the difficulty herein involves the fact that many of these characteristics are identified risk factors or correlates of MCI, and some (e.g., income, education, and premorbid IQ) likely underlie its clinical manifestation if viewed as proxies of cognitive reserve (Artero et al., 2008; Carrillo et al., 2009; Duda, Puente, & Miller, 2014; Katz et al., 2012; Sattler, Toro, Schönknecht, & Schröder, 2012; Stern, 2009). A potential effect of these characteristics may have been to serve as confounds in our primary analyses by facilitating or obscuring group differences. Where group characteristics were related to the dependent variable of interest, however, our results remained significant after statistically controlling for these characteristics. We elected not to control for race given the small number of African Americans in our sample, though speculate that in controlling for other characteristics, race was controlled for by proxy given that African Americans in our sample displayed significantly lower income, educational attainment, and premorbid IQ than Caucasians ($p < .05$). In addition, we re-analyzed our data with African Americans excluded from the sample and found a nearly identical pattern of statistically significant results and effect sizes. Nonetheless, it will be important for future studies to replicate our findings in carefully matched groups.

In short, the present study had important sample limitations and the implementation of discounting tasks in clinical settings is still fairly distant on the horizon. Nonetheless, our results support behavioral economics as a worthwhile avenue to continue to

explore while marking an important step in the advancement of knowledge regarding discounting and, more generally, decision-making in cognitively impaired older adults. Our findings reaffirm previous literature suggesting that early phases of AD are associated with inconsistent cognitive templates for risk-based preferences. While past studies have demonstrated impulsivity changes in early AD, impulsivity is a multidimensional construct (Evenden, 1999) and previous research has focused largely on personality measures and neuropsychological test performance (e.g., Rochat et al., 2013). The present study extends these findings to a unique facet of impulsivity by providing a performance-based assessment of the extent to which an individual forgoes long-term benefits for immediate gains. Although preliminary, the observation of disease-associated differences in this aspect of impulsivity suggests potential to complement available diagnostic instruments in the early detection of dementia.

Conflict of Interest

None declared.

References

Acker, J., Amlung, M., Stojek, M., Murphy, J. G., & MacKillop, J. (2012). Individual variation in behavioral economic indices of the relative value of alcohol: Incremental validity in relation to impulsivity, craving, and intellectual functioning. *Journal of Experimental Psychopathology*, *3 (3)*, 423–436.

Albert, M. S., DeKosky, S. T., Dickson, D., Dubois, B., Feldman, H. H., Fox, N. C., et al. (2011). The diagnosis of mild cognitive impairment due to Alzheimer's disease: Recommendations from the National Institute on Aging-Alzheimer's Association workgroups on diagnostic guidelines for Alzheimer's disease. *Alzheimer's & Dementia: The Journal of the Alzheimer's Association*, *7 (3)*, 270–279.

Albert, M. S., Moss, M. B., Tanzi, R., & Jones, K. (2001). Preclinical prediction of AD using neuropsychological tests. *Journal of the International Neuropsychological Society*, *7 (5)*, 631–639.

Alessi, S., & Petry, N. (2003). Pathological gambling severity is associated with impulsivity in a delay discounting procedure. *Behavioural Processes*, *64 (3)*, 345–354.

Alzheimer's Association. (2013). Alzheimer's disease facts and figures. *Alzheimer's and Dementia: The Journal of the Alzheimer's Association*, *9 (2)*, 1–71.

Amlung, M., & MacKillop, J. (2011). Delayed reward discounting and alcohol misuse: The roles of response consistency and reward magnitude. *Journal of Experimental Psychopathology*, *2 (3)*, 418–431.

Amlung, M. T., Sweet, L. H., Acker, J. D., Brown, C. L., & MacKillop, J. (2013). Dissociable brain signatures of choice conflict and immediate reward preferences in alcohol use disorders. *Addiction Biology*, *19 (4)*, 743–753.

Artero, S., Ancelin, M.-L., Portet, F., Dupuy, A., Berr, C., Dartigues, J.-F., et al. (2008). Risk profiles for mild cognitive impairment and progression to dementia are gender specific. *Journal of Neurology, Neurosurgery & Psychiatry*, *79 (9)*, 979–984.

Ashendorf, L., Jefferson, A. L., O'Connor, M. K., Chaisson, C., Green, R. C., & Stern, R. A. (2008). Trail making test errors in normal aging, mild cognitive impairment, and dementia. *Archives of Clinical Neuropsychology: The Official Journal of the National Academy of Neuropsychologists*, *23 (2)*, 129–137.

Avsar, K. B., Weller, R. E., Cox, J. E., Reid, M. A., White, D. M., & Lahti, A. C. (2013). An fMRI investigation of delay discounting in patients with schizophrenia. *Brain and Behavior*, *3 (4)*, 384–401.

Barkley, R. A., Edwards, G., Laneri, M., Fletcher, K., & Metevia, L. (2001). Executive functioning, temporal discounting, and sense of time in adolescents with attention deficit hyperactivity disorder (ADHD) and oppositional defiant disorder (ODD). *Journal of Abnormal Child Psychology*, *29 (6)*, 541–556.

Baudic, S., Barba, G. D., Thibaudet, M. C., Smagghe, A., Remy, P., & Traykov, L. (2006). Executive function deficits in early Alzheimer's disease and their relations with episodic memory. *Archives of Clinical Neuropsychology*, *21 (1)*, 15–21.

Bechara, A. (2005). Decision making, impulse control, and loss of willpower to resist drugs: A neurocognitive perspective. *Nature Neuroscience*, *8*, 1458–1463.

Belleville, S., Chertkow, H., & Gauthier, S. (2007). Working memory and control of attention in persons with Alzheimer's disease and mild cognitive impairment. *Neuropsychology*, *21 (4)*, 458–469.

Belleville, S., Rouleau, N., & Van der Linden, M. (2006). Use of the Hayling task to measure inhibition of prepotent responses in normal aging and Alzheimer's disease. *Brain and Cognition*, *62 (2)*, 113–119.

Benzion, U., Rapoport, A., & Yagil, J. (1989). Discount rates inferred from decisions: An experimental study. *Management Science*, *35*, 270–284.

Bickel, W. K., & Marsch, L. A. (2001). Toward a behavioral economic understanding of drug dependence: Delay discounting processes. *Addiction*, *96*, 73–86.

Bickel, W. K., Marsch, L. A., & Carroll, M. E. (2000). Deconstructing relative reinforce efficacy and situating the measures of reinforcement with behavioral economics: A theoretical proposal. *Psychopharmacology (Berlin)*, *153*, 44–56.

Bickel, W. K., Miller, M. L., Yi, R., Kowal, B. P., Lindquist, D. M., & Pitcock, J. A. (2007). Behavioral and neuroeconomics of drug addiction: Competing neural systems and temporal discounting processes. *Drug and Alcohol Dependence*, *90(Suppl. 1)*, S85–S91.

Bickel, W. K., Odum, A. L., & Madden, G. J. (1999). Impulsivity and cigarette smoking: Delay discounting in current, never, and ex-smokers. *Psychopharmacology*, *146*, 447–454.

Bickel, W. K., Yi, R., Landes, R. D., Hill, P. F., & Baxter, C. (2011). Remember the future: Working memory training decreases delay discounting among stimulant addicts. *Biological Psychiatry*, *69 (3)*, 260–265.

Bidewell, J., Griffin, B., & Hesketh, B. (2006). Timing of retirement: Including a delay discounting perspective in retirement models. *Journal of Vocational Behavior*, *68 (2)*, 368–387.

Black, A. C., & Rosen, M. I. (2011). A money management-based substance use treatment increases valuation of future rewards. *Addictive Behaviors*, *36(1–2)*, 125–128.

Bobova, L., Finn, P. R., Rickert, M. E., & Lucas, J. (2009). Disinhibitory psychopathology and delay discounting in alcohol dependence: Personality and cognitive correlates. *Experimental and Clinical Psychopharmacology*, *17 (1)*, 51–61.

Bondi, M. W., Serody, A. B., Chan, A. S., Eberson-Shumate, S. C., Delis, D. C., Hansen, L. A., et al. (2002). Cognitive and neuropathologic correlates of Stroop Color-Word Test performance in Alzheimer's disease. *Neuropsychology*, *16*, 335–343.

Borson, S., Frank, L., Bayley, P. J., Boustani, M., Dean, M., Lin, P.-J., et al. (2013). Improving dementia care: The role of screening and detection of cognitive impairment. *Alzheimer's & Dementia*, *9 (2)*, 151–159.

Brand, M., Fujiwara, E., Borsutzky, S., Kalbe, E., Kessler, J., & Markowitsch, H. J. (2005). Decision-making deficits of Korsakoff patients in a new gambling task with explicit rules: Associations with executive functions. *Neuropsychology*, *19*, 267–277.

Brandt, J., Aretouli, E., Neijstrom, E., Samek, J., Manning, K., Albert, M. S., et al. (2009). Selectivity of executive function deficits in mild cognitive impairment. *Neuropsychology*, *23 (5)*, 607–618.

Busse, A., Hensel, A., Guhne, U., Angermeyer, M. C., & Riedel-Heller, S. (2006). Mild cognitive impairment—long-term course of four clinical subtypes. *Neurology*, *67*, 2176–2185.

Carrillo, M. C., Blackwell, A., Hampel, H., Lindborg, J., Sperling, R., Schenk, D., et al. (2009). Early risk assessment for Alzheimer's disease. *Alzheimer's and Dementia*, *5 (2)*, 182–196.

Chen, T. F., Chen, Y. F., Cheng, T. W., Hua, M. S., Liu, H. M., & Chiu, M. J. (2009). Executive dysfunction and periventricular diffusion tensor changes in amnesic mild cognitive impairment and early Alzheimer's disease. *Human Brain Mapping*, *30 (11)*, 3826–3836.

Cinnamon, L., MacKillop, J., Murphy, J. G., Grenga, A., Swift, R. M., & McGeary, J. E. (2013). Biphasic effects of alcohol on delay and probability discounting. *Experimental and Clinical Psychopharmacology*, *21 (3)*, 214–221.

Coffey, S. F., Gudleski, G. D., Saladin, M. E., & Brady, K. T. (2003). Impulsivity and rapid discounting of delayed hypothetical rewards in cocaine-dependent individuals. *Experimental and Clinical Psychopharmacology*, *11*, 18–25.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. 2nd ed. Hillsdale, NJ: Lawrence Earlbaum Associates.

Cools, R., Barker, R. A., Sahakian, B. J., & Robbins, T. W. (2003). L-Dopa medication remediates cognitive inflexibility, but increases impulsivity in patients with Parkinson's disease. *Neuropsychologia*, *41*, 1431–1441.

Daugherty, J. R., & Brase, G. L. (2010). Taking time to be healthy: Predicting health behaviors with delay discounting and time perspective. *Personality and Individual Differences*, *48 (2)*, 202–207.

Delazer, M., Sinz, H., Zamarian, L., & Benke, T. (2007). Decision-making with explicit and stable rules in mild Alzheimer's disease. *Neuropsychologia*, *45 (8)*, 1632–1641.

Delis, D., Kaplan, E., & Kramer, J. (2001). *Delis-Kaplan executive function system*. San Antonio, TX: Harcourt Brace & Company.

Denberg, N., Bechara, A., Tranel, A., Hindes, A., & Damasio, A. (1999). Neuropsychological evidence for why the ability to decide advantageously decreases with age. *Society for Neuroscience Abstracts*, *21*, 24.

Denburg, N. L., Tranel, D., & Bechara, A. (2005). The ability to decide advantageously declines prematurely in some normal older persons. *Neuropsychologia*, *43 (7)*, 1099–1106.

Dixon, M. R., Marley, J., & Jacobs, E. A. (2003). Delay discounting by pathological gamblers. *Journal of Applied Behavior Analysis*, *36 (4)*, 449–458.

Dror, I. E., Katona, M., & Mungur, K. (1998). Age differences in decision making: To take a risk or not? *Gerontology*, *44 (2)*, 67–71.

Du, W., Green, L., & Myerson, J. (2002). Cross-cultural comparisons of discounting delayed and probabilistic rewards. *The Psychological Record*, *52 (4)*, 479–492.

Duckworth, A. L., & Seligman, M. E. P. (2005). Self-discipline outdoes IQ in predicting academic performance of adolescents. *Psychological Science*, *16 (12)*, 939–944.

Duda, B., Puente, A. N., & Miller, L. S. (2014). Cognitive reserve moderates relation between global cognition and functional status in older adults. *Journal of Clinical and Experimental Neuropsycholology*, *36 (4)*, 368–378.

Duff, K., Humphreys Clark, J. D., O'Bryant, S. E., Mold, J. W., Schiffer, R. B., & Sutker, P. B. (2008). Utility of the RBANS in detecting cognitive impairment associated with Alzheimer's disease: Sensitivity, specificity, and positive and negative predictive powers. *Archives of Clinical Neuropsychology*, *23 (5)*, 603–612.

Estle, S. J., Green, L., Myerson, J., & Holt, D. D. (2006). Differential effects of amount on temporal and probability discounting of gains and losses. *Memory and Cognition*, *34 (4)*, 914–928.

Evenden, J. L. (1999). Varieties of impulsivity. *Psychopharmacology*, *146 (4)*, 348–361.

Ewers, M., Walsh, C., Trojanowski, J. Q., Shaw, L. M., Petersen, R. C., Jack, C. R., et al. (2012). Prediction of conversion from mild cognitive impairment to Alzheimer's disease dementia based upon biomarkers and neuropsychological test performance. *Neurobiology of Aging*, *33 (7)*, 1203–1214.

Fernández-Ballesteros, R., Zamarrón, M. D., & Tàrraga, L. (2005). Learning potential: A new method for assessing cognitive impairment. *International Psychogeriatrics*, *17 (1)*, 119–128.

Folstein, M., Folstein, M., McHugh, P. R., & Fanjiang, G. (2000). *The Mini-Mental State Examination*. Odessa, FL: Psychological Assessment Resources.

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-Mental State:" A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*, 189–198.

Fox, L. S., Olin, J. T., Erblich, J., Ippen, C. G., & Schneider, L. S. (1998). Severity of cognitive impairment in Alzheimer's disease affects list learning using the California Verbal Learning Test (CVLT). *International Journal of Geriatric Psychiatry*, *13 (8)*, 544–549.

Genon, S., Collette, F., Moulin, C. J. A., Lekeu, F., Bahri, M. A., Salmon, E., et al. (2013). Verbal learning in Alzheimer's disease and mild cognitive impairment: Fine-grained acquisition and short-delay consolidation performance and neural correlates. *Neurobiology of Aging*, *34 (2)*, 361–373.

Green, L., Fry, A. F., & Myerson, J. (1994). Discounting of delayed rewards: A life-span comparison. *Psychological Science*, *5 (1)*, 33–36.

Green, L., Myerson, J., Lichtman, D., Rosen, S., & Fry, A. (1996). Temporal discounting in choice between delayed rewards: The role of age and income. *Psychology and Aging*, *11 (1)*, 79–84.

Harrison, G. W., Lau, M. I., & Williams, M. B. (2002). Estimating individual discount rates in Denmark: A field experiment. *American Economic Review*, *92 (5)*, 1606–1617.

Henninger, D. E., Madden, D. J., & Huettel, S. A. (2010). Processing speed and memory mediate age-related differences in decision making. *Psychology and Aging*, *25 (2)*, 262–270.

Hinson, J. M., Jameson, T. L., & Whitney, P. (2003). Impulsive decision making and working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29 (2)*, 298–306.

Hoffman, W. F., Moore, M., Templin, R., McFarland, B., Hitzemann, R. J., & Mitchell, S. H. (2006). Neuropsychological functions and delay discounting in methamphetamine-dependent individuals. *Psychopharmacology*, *188*, 162–170.

Holmes, J. A., Johnson, J. L., & Roedel, A. L. (1993). Impulsivity in adult neurobehavioral disorders. In W. G. McCown, J. L. Johnson, & M. B. Shure (Eds.), *the impulsive client: Theory, research, treatment* (pp. 309–321). Washington, DC: American Psychological Association.

Holt, D. D., Green, L., & Myerson, J. (2003). Is discounting impulsive? Evidence from temporal and probability discounting in gambling and non-gambling college students. *Behavioural Processes*, *64*, 355–367.

Huckans, M., Seelye, A., Woodhouse, J., Parcel, T., Mull, L., Schwartz, D., et al. (2011). Discounting of delayed rewards and executive dysfunction in individuals infected with hepatitis C. *Journal of Clinical and Experimental Neuropsychology*, *33 (2)*, 176–186.

Hurd, M. D., Martorell, P., Delavande, A., Mullen, K. J., & Langa, K. M. (2013). Monetary costs of dementia in the United States. *New England Journal of Medicine*, *368 (14)*, 1326–1334.

Inquisit 3.0.6.0 [Computer Software]. (2011). Seattle, WA: Millisecond Software.

Jacobson, S., & Petrie, R. (2009). Learning from mistakes: What do inconsistent choices over risk tell us? *Journal of Risk and Uncertainty*, *38 (2)*, 143–158.

Johnson, M. W., & Bickel, W. K. (2008). An algorithm for identifying nonsystematic delay-discounting data. *Experimental and Clinical Psychopharmacology*, *16 (3)*, 264–274.

Katz, M. J., Lipton, R. B., Hall, C. B., Zimmerman, M. E., Sanders, A. E., Verghese, J., et al. (2012). Age-specific and sex-specific prevalence and incidence of mild cognitive impairment, dementia, and Alzheimer dementia in Blacks and Whites: A report from the Einstein Aging Study. *Alzheimer Disease & Associated Disorders*, *26 (4)*, 335–343.

Kirby, K. N. (1997). Bidding on the future: Evidence against normative discounting of delayed rewards. *Journal of Experimental Psychology: General*, *126*, 54–70.

Kirby, K. N., Godoy, R., Reyes-García, V., Byron, E., Apaza, L., Leonard, W., et al. (2002). Correlates of delay-discount rates: Evidence from Tsimane' Amerindians of the Bolivian rain forest. *Journal of Economic Psychology*, *23 (3)*, 291–316.

Kirby, K. N., & Petry, N. M. (2004). Heroin and cocaine abusers have higher discount rates for delayed rewards than alcoholics or non-drug-using controls. *Addiction (Abingdon, England)*, *99 (4)*, 461–471.

Kirby, K. N., Petry, N. M., & Bickel, W. K. (1999). Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls. *Journal of Experimental Psychology: General*, *128 (1)*, 78–87.

Kirby, K. N., Winston, G. C., & Santiesteban, M. (2005). Impatience and grades: Delay-discount rates correlate negatively with college GPA. *Learning and Individual Differences*, *15 (3)*, 213–222.

Kohannim, O., Hua, X., Hibar, D. P., Lee, S., Chou, Y.-Y., Toga, A. W., et al. (2010). Boosting power for clinical trials using classifiers based on multiple biomarkers. *Neurobiology of Aging*, *31 (8)*, 1429–1442.

Kollins, S. H. (2003). Delay discounting is associated with substance use in college students. *Addictive Behaviors*, *28 (6)*, 1167–1173.

Kovalchik, S., Camerer, C. F., Grether, D. M., Plott, C. R., & Allman, J. M. (2005). Aging and decision making: A comparison between neurologically healthy elderly and young individuals. *Journal of Economic Behavior & Organization*, *58 (1)*, 79–94.

Kumar, A. (2009). Who gambles in the stock market? *The Journal of Finance*, *64 (4)*, 1889–1933.

Lambon, R. M., Patterson, K., Graham, N., Dawson, K., & Hodges, J. (2003). Homogeneity and heterogeneity in mild cognitive impairment and Alzheimer's disease: A cross-sectional and longitudinal study of 55 cases. *Brain*, *126*, 2350–2362.

Logie, R., Cocchini, G., Della Sala, S., & Baddeley, A. (2004). Is there a specific executive capacity for dual task coordination? Evidence from Alzheimer's disease. *Neuropsychology*, *18*, 504–513.

MacKillop, J., Anderson, E. J., Castelda, B. A., Mattson, R. E., & Donovick, P. J. (2006). Divergent validity of measures of cognitive distortions, impulsivity, and time perspective in pathological gambling. *Journal of Gambling Studies*, *22*, 339–354.

MacKillop, J., Miranda, R., Jr., Monti, P. M., Ray, L. A., Murphy, J. G., Rohsenow, D. J., et al. (2010). Alcohol demand, delayed reward discounting, and craving in relation to drinking and alcohol use disorders. *Journal of Abnormal Psychology*, *119 (1)*, 106–114.

Madden, G. J., Petry, N. M., & Johnson, P. S. (2009). Pathological gamblers discount probabilistic rewards less steeply than matched controls. *Experimental and Clinical Psychopharmacology*, *17*, 283–290.

Mather, M. (2006). A review of decision-making processes: Weighing the risks and benefits of aging. In L. L. Carstensen, & C. R. Hartel (Eds.), When I'm 64. (pp. 145–173). Washington, DC: The National Academies Press.

Mazur, J. (1987). An adjusting procedure for delayed reinforcement. In M. Commons, J. Mazur, J. Nevin, & H. Rachlin (Eds.), *The effect of delay and of intervening events on reinforcement value* (pp. 55–73). Erlbaum, NJ: Lawrence Erlbaum Associates, Inc.

McKay, C., Casey, J. E., Wertheimer, J., & Fichtenberg, N. L. (2007). Reliability and validity of the RBANS in a traumatic brain injured sample. *Archives of Clinical Neuropsychology*, *22 (1)*, 91–98.

Morris, J. C. (2005). Early-stage and preclinical Alzheimer disease. *Alzheimer Disease and Associated Disorders*, *19*, 163–165.

Moulin, C. J. A., James, N., Freeman, J. E., & Jones, R. W. (2004). Deficient acquisition and consolidation: Intertrial free recall performance in Alzheimer's disease and mild cognitive impairment. *Journal of Clinical and Experimental Neuropsychology*, *26 (1)*, 1–10.

Myerson, J., Green, L., & Warusawitharana, M. (2001). Area under the curve as a measure of discounting. *Journal of the Experimental Analysis of Behavior*, *76 (2)*, 235–243.

Odum, A. L., Madden, G. J., Badger, G. J., & Bickel, W. K. (2000). Needle sharing in opioid dependent outpatients: Psychological processes underlying risk. *Drug and Alcohol Dependence*, *60*, 259–266.

Ohmura, Y., Takahashi, T., & Kitamura, N. (2005). Discounting delayed and probabilistic monetary gains and losses by smokers of cigarettes. *Psychopharmacology*, *182 (4)*, 508–515.

Ohmura, Y., Takahashi, T., Kitamura, N., & Wehr, P. (2006). Three-month stability of delay and probability discounting measures. *Experimental and Clinical Psychopharmacology*, *14 (3)*, 318–328.

Olson, E. A., Hooper, C. J., Collins, P., & Luciana, M. (2007). Adolescents' performance on delay and probability discounting tasks: Contributions of age, intelligence, executive functioning, and self-reported externalizing behavior. *Personality and Individual Differences*, *43 (7)*, 1886–1897.

Pennanen, C., Kivipelto, M., Tuomainen, S., Hartikainen, P., Hänninen, T., Laakso, M. P., et al. (2004). Hippocampus and entorhinal cortex in mild cognitive impairment and early AD. *Neurobiology of Aging*, *25 (3)*, 303–310.

Perry, R. J., Watson, P., & Hodges, J. R. (2000). The nature and staging of attention dysfunction in early (minimal and mild) Alzheimer's disease: Relationship to episodic and semantic memory impairment. *Neuropsychologia*, *38 (3)*, 252–271.

Petersen, R. C., Doody, R., Kurz, A., Mohs, R. C., Morris, J. C., Rabins, P. V., et al. (2001). Current concepts in mild cognitive impairment. *Archives of Neurology*, *58 (12)*, 1985–1992.

Petersen, R. C., Roberts, R. O., Knopman, D. S., Boeve, B. F., Geda, Y. E., Ivnik, R. J., et al. (2009). Mild cognitive impairment: Ten years later. *Archives of Neurology*, *66 (12)*, 1447–1455.

Petersen, R. C., Smith, G. E., Ivnik, R. J., Kokmen, E., & Tangalos, E. G. (1994). Memory function in very early Alzheimer's disease. *Neurology*, *44*, 867–872.

Petry, N. M. (2001). Delay discounting of money and alcohol in actively using alcoholics, currently abstinent alcoholics, and controls. *Psychopharmacology*, *154*, 243–250.

Petry, N. M. (2002). Discounting of delayed rewards in substance abusers: Relationship to antisocial personality disorder. *Psychopharmacology (Berlin)*, *162 (4)*, 425–432.

Petry, N. M. (2012). Discounting of probabilistic rewards is associated with gambling abstinence in treatment-seeking pathological gamblers. *Journal of Abnormal Psychology*, *121 (1)*, 151–159.

Prasad, K., & Salmon, T. C. (2013). Self selection and market power in risk sharing contracts. *Journal of Economic Behavior & Organization*, *90*, 71–86.

Rachlin, H., Raineri, A., & Cross, D. (1991). Subjective probability and delay. *Journal of the Experimental Analysis of Behavior*, *55 (2)*, 233–244.

Raineri, A., & Rachlin, H. (1993). The effect of temporal constraints on the value of money and other commodities. *Journal of Behavioral Decision Making*, *6*, 77–94.

Randolph, C. (1998). *Repeatable battery for the assessment of neuropsychological status.* San Antonio, TX: The Psychological Corporation.

Rapoport, S. I. (2003). Coupled reductions in brain oxidative phosphorylation and synaptic function can be quantified and staged in the course of Alzheimer disease. *Neurotoxicity Research*, *5 (6)*, 385–397.

Read, D., & Read, N. (2004). Time discounting over the lifespan. *Organizational Behavior and Human Decision Processes*, *94 (1)*, 22–32.

Reimers, S., Maylor, E. A., Stewart, N., & Chater, N. (2009). Associations between a one-shot delay discounting measure and age, income, education and real-world impulsive behavior. *Personality and Individual Differences*, *47 (8)*, 973–978.

Reynolds, B., Richards, J. B., Horn, K., & Karraker, K. (2004). Delay discounting and probability discounting as related to cigarette smoking status in adults. *Behavioral Processes*, *65*, 35–42.

Richards, J. B., Zhang, L., Mitchell, S. H., & de Wit, H. (1999). Delay or probability discounting in a model of impulsive behavior: Effect of alcohol. *Journal of the Experimental Analysis of Behavior*, *71 (2)*, 121–143.

Roalf, D. R., Mitchell, S. H., Harbaugh, W. T., & Janowsky, J. S. (2011). Risk, reward, and economic decision making in aging. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *67B (3)*, 289–298.

Rochat, L., Billieux, J., Juillerat Van der Linden, A.-C., Annoni, J.-M., Zekry, D., Gold, G., et al. (2013). A multidimensional approach to impulsivity changes in mild Alzheimer's disease and control participants: Cognitive correlates. *Cortex*, *49 (1)*, 90–100.

Sattler, C., Toro, P., Schönknecht, P., & Schröder, J. (2012). Cognitive activity, education and socioeconomic status as preventive factors for mild cognitive impairment and Alzheimer's disease. *Psychiatry Research*, *196 (1)*, 90–95.

Saunders, N. L. J., & Summers, M. J. (2010). Attention and working memory deficits in mild cognitive impairment. *Journal of Clinical and Experimental Neuropsychology*, *32 (4)*, 350–357.

Shamosh, N. A., DeYoung, C. G., Green, A. E., Reis, D. L., Johnson, M. R., Conway, A. R. A., et al. (2008). Individual differences in delay discounting: Relation to intelligence, working memory, and anterior prefrontal cortex. *Psychological Science*, *19 (9)*, 904–911.

Simpson, C. A., & Vuchinich, R. E. (2000). Reliability of a measure of temporal discounting. *The Psychological Record*, *50 (1)*, 3–16.

Singh, V., Chertkow, H., Lerch, J. P., Evans, A. C., Dorr, A. E., & Kabani, N. J. (2006). Spatial patterns of cortical thinning in mild cognitive impairment and Alzheimer's disease. *Brain*, *129 (11)*, 2885–2893.

Sinz, H., Zamarian, L., Benke, T., Wenning, G. K., & Delazer, M. (2008). Impact of ambiguity and risk on decision making in mild Alzheimer's disease. *Neuropsychologia*, *46 (7)*, 2043–2055.

Stern, Y. (2009). Cognitive reserve. *Neuropsychologia*, *47 (10)*, 2015–2028.

Stopford, C. L., Thompson, J. C., Neary, D., Richardson, A. M. T., & Snowden, J. S. (2012). Working memory, attention, and executive function in Alzheimer's disease and frontotemporal dementia. *Cortex*, *48 (4)*, 429–446.

Stout, J. C., Rodawalt, W. C., & Siemers, E. R. (2001). Risky decision-making in Huntington's disease. *Journal of the International Neuropsychological Society*, *7*, 92–101.

Tabachnick, B. G., & Fidell, L. S. (2004). *Using multivariate statistics* (4th ed.). Needham Heights, MA: Allyn & Bacon.

Thaler, R. (1981). Some empirical evidence on dynamic inconsistency. *Economic Letters*, *8*, 201–207.

The Psychological Corporation. (2001). *Wechsler test of adult reading*. San Antonio, TX: Harcourt Brace & Company.

Torralva, T., Kipps, C. M., Hodges, J. R., Clark, L., Bekinschtein, T., Roca, M., et al. (2007). The relationship between affective decision-making and theory of mind in the frontal variant of fronto-temporal dementia. *Neuropsychologia*, *45 (2)*, 342–349.

Twamley, E. W., Ropacki, S., & Bondi, M. W. (2006). Neuropsychological and neuroimaging changes in preclinical Alzheimer's disease. *Journal of the International Neuropsychological Society*, *12 (5)*, 707–735.

Vuchinich, R. E., & Simpson, C. A. (1998). Hyperbolic temporal discounting in social drinkers and problem drinkers. *Experimental and Clinical Psychopharmacology*, *6*, 292–305.

Wadley, V. G., Okonkwo, O., Crowe, M., & Ross-Meadows, L. A. (2008). Mild cognitive impairment and everyday function: Evidence of reduced speed in performing instrumental activities of daily living. *The American Journal of Geriatric Psychiatry: Official Journal of the American Association for Geriatric Psychiatry*, *16 (5)*, 416–424.

Wechsler, D. (2001). *Wechsler test of adult reading: WTAR*. San Antonio, TX: The Psychological Corporation.

Weiner, M. W., Veitch, D. P., Aisen, P. S., Beckett, L. A., Cairns, N. J., Green, R. C., et al. (2012). The Alzheimer's disease neuroimaging initiative: A review of papers published since its inception. *Alzheimer's & Dementia: The Journal of the Alzheimer's Association*, *8(1 Suppl.)*, S1–68.

Zamarian, L., Weiss, E. M., & Delazer, M. (2011). The impact of mild cognitive impairment on decision making in two gambling tasks. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *66B (1)*, 23–31.

Zermatten, A., Van der Linden, M., d'Acremont, M., Jermann, F., & Bechara, A. (2005). Impulsivity and decision making. *The Journal of nervous and mental disease*, *193 (10)*, 647–650.