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Discounting of Delayed and Probabilistic Outcomes Across the Adult Lifespan

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by
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ABSTRACT OF THE THESIS

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Intertemporal and risky decision-making predicts many problem behaviors that also decline with age, raising the question: Do intertemporal and risky decisions change with age? Despite the theoretical and empirical importance, the literature under both rubrics reveals inconsistent findings. Some studies suggest that these inconsistencies may be due to the presence of unassessed demographic differences. The present study examined age differences, evaluating the role of demographic variables in intertemporal and risky choice of gains and losses using the discounting framework. Four experiments were conducted, each with one of the four types of discounting: discounting of delayed gains, discounting of delayed losses, discounting of probabilistic gains, and discounting of probabilistic losses. Although individuals across the lifespan discounted the delayed and probabilistic outcomes in fundamentally similar ways, which were described by the hyperboloid discounting function, age differences in decision-making emerged: older adults chose larger, later rewards and smaller, sooner payment more often than younger adults, whereas there were no age-related differences in the discounting of probabilistic outcomes. In addition, income neither affected degree of discounting nor moderated the age effect in the discounting of probabilistic outcomes, but an age effect was evident in some income groups in the discounting of delayed outcomes: Older adults with lower income chose larger, later rewards more often than younger adults with lower incomes, whereas older adults with higher income chose smaller, sooner payments more often than younger adults with higher incomes.

Chapter 1: Introduction

Financial decisions are critical not only for the quality of one's life but also one's life expectancy. Higher income is associated with greater longevity (Chetty et al., 2016), while lower income is associated with higher rates of physical limitation, heart disease, diabetes, stroke, and other chronic conditions (Blackwell et al., 2014). Financial decisions made prior to retirement play a major role in determining the quality of life as an older adult. Although retirement policies and saving plans were proposed and implemented to establish the capability and habit of savings (e.g., Setting Every Community Up for Retirement Enhancement [SECURE] and SECURE 2.0), personal saving rate in the United States has been extremely low, which was barely 3.5% as of July 2023 (U. S. Bureau of Economic Analysis, 2020). According to a new report from the National Institute on Retirement Security, many Generation Xers are failing to meet retirement saving targets, and a typical Generation X household has only $40,000 in retirement savings in private accounts (Bond et al., 2023). Not unexpectedly, financial decisions are even more important for older adults, who may not be able to earn back the money lost. In the past several years, relevant resources have been provided (e.g., U.S. Department of Justice, 2016) and many states have introduced legislation (Bergal, 2014) to protect older adults from fraud and financial exploitation. Despite the importance of financial decision-making across the lifespan, age-related differences in decision-making are not well understood, in part because of a lack of consensus regarding age-related differences in decision-making itself.

Fundamental decision-making processes are typically divided into two categories: intertemporal choice and risky choice, depending on whether the outcomes are delayed or probabilistic. Despite their empirical importance, there has been a lack of consensus in the literature as to whether there are age-related differences in intertemporal and risky decision. With respect to

intertemporal choice, although no age-related difference was observed in the intertemporal choice of losses (Halfmann et al., 2013; Löckenhoff et al., 2011), the literature on intertemporal choice of rewards revealed inconsistent findings. Some studies observed no age-related difference (Chao et al., 2009; Rieger & Mata, 2015), others found older adults tended to choose smaller, sooner rewards (Kirby et al., 2002; Read & Read, 2004), while yet others reported that older adults tended to choose later, larger rewards (Green et al., 1994; Löckenhoff et al., 2011) more than younger adults. These diverse findings led Seaman et al. (2022) to conduct a meta-analysis, and they reported no sizable age-related difference in the degree to which people discount the value of delayed rewards.

Nonetheless, the results from some studies suggest that the heterogeneity in the literature on intertemporal choice of rewards might be due to the demographic differences in the samples. For example, some studies found that socioeconomic status was a strong predictor of intertemporal decision-making in younger adults (Yeh et al., 2021) and suggested that income might interact with age (Green et al., 1996). A recent study from our laboratory (Wan et al., *under review*) compared younger (35-50) and older (65-80) adults with lower (annual household income less than $50K) and higher incomes (annual household income more than $80K) and found clear age differences in those with lower incomes but not those with higher incomes. Similar to the findings with intertemporal choice of rewards, age differences in the intertemporal choice of losses may also interact with demographic differences (e.g., socioeconomic status). Bickel et al. (2016), for example, examined the effect of resource availability on the degree to which people discount the value of delayed losses and found that participants discounted delayed losses at a higher rate under a scenario in which they had scarce resources and discounted at a lower rate under a scenario in which they had sufficient resources.

With respect to risky choice, a meta-analysis reported no age-related differences unless participants had to learn outcome likelihoods from experience (Mata et al., 2011), although a study of more than 20,000 adults that was not included in that meta-analysis revealed a strong trend towards less risk-taking as a function of age (Dohmen et al., 2011). Some studies, however, reported an interaction between demographic differences and age with risky choice, suggesting that mixed findings in the risky choice literature may be due to the presence of unassessed demographic differences. Unfortunately, a moderation effect of demographic variables on age also has been unclear. For example, Dohmen et al. (2005) observed that females were more risk-averse than males and that males' willingness to take risks changed more than females' with age such that gender differences were much smaller in older adults. In contrast, a recent meta-analysis failed to reveal a moderation effect of gender with age on risky choice (Defoe et al., 2015). Likewise, for socioeconomic status, Griskevicius et al. (2011) reported that individuals who grew up relatively poor gamble for big rewards more often, whereas individuals who grew up relatively wealthy were more likely to avoid risky gambles. Von Gaudecker et al. (2011), on the other hand, conducted an experiment with more than 1,400 participants and failed to observe an income and wealth effect on risky choices.

In contrast to studies of intertemporal choice, the outcome in studies of risky choice typically involve both gains and losses (e.g., Probabilistic Gambling Task and Iowa Gambling Task). Despite its ecological validity, it is well established that people evaluate gains and losses in different ways and that risky choices of gains and losses involve different underlying processes (Green & Myerson, 2013). Indeed, Rutledge et al. (2016) found age-related differences in risky choice with gains but not with losses. Mather et al. (2012) found that older adults were more risk averse with gains and more risk seeking with losses (i.e., "certainty effect"). These results

suggest that age has different effects depending on whether the outcome is a gain or a loss, although it remains unclear whether there is an age effect on the risky choice of positive outcomes, negative outcomes, or both, and whether the effect of age in one domain has a stronger impact on risky choice than in the other.

The goal of the present study was to examine age-related differences in four domains of decision-making that may underlie decisions in everyday life: intertemporal choice of gains and losses, and risky choice of gains and losses, studied within a discounting framework. The discounting framework (Green & Myerson, 2004) involves using similar experimental procedures to establish the subjective value of delayed or probabilistic outcomes and modeling the evaluation of such outcomes in analogous ways. *Delay discounting* refers to the fact that when an outcome is delayed, its subjective value decreases, and *probability discounting* refers to the fact that when an outcome is probabilistic, its subjective value decreases. Delay and probability discounting have both been shown to be well accommodated by the hyperboloid discounting model (Myerson & Green, 1995):

$$V = A/(1 + bX)^s, \tag{1.1}$$

where V is the subjective value of an outcome of amount A that is available after a delay or probability, X. The parameter b governs the rate at which the value of the outcome is discounted, and s is a scaling parameter. Importantly, studies have shown that the degree of discounting of delayed or probabilistic outcomes predicts a wide range of financial decisions and consequences, such as wealth (Huffman et al., 2019), creditworthiness (Meier & Sprenger, 2012), retirement saving (Bradford et al., 2017), and gambling (Holt et al., 2003).

The increased risk associated with advancing age (e.g., death) may affect the degree of discounting. With respect to the discounting of delayed rewards, for example, older adults may discount the delayed reward at a lower rate than younger adults at short delays but discount at a higher rate than younger adults at long delays because older adults might not expect to survive to collect the delayed reward. The present study used an adjusting-amount discounting procedure (Du et al., 2002) to examine the effect of age on the parameters of the hyperboloid discounting function. The adjusting-amount procedure was used to estimate the subjective value of delayed and probabilistic outcomes at various delays and probabilities with an online sample of participants. The procedure using online samples has been empirically shown to meet psychometric standards for reliability and construct validity (Wan et al., 2023).

Similar to financial decision-making, health-related decisions such as social distancing and vaccination also involve intertemporal and risky choices. Psychological distress, in particular, has emerged as a critical factor in health-related decisions. Myerson et al. (2022) showed that the likelihood of engaging in mitigation behaviors decreased while the likelihood of being vaccinated increased as a function of psychological distress. In addition, recent research reported that steeper discounting was associated with a lower likelihood of vaccination (Halilova et al., 2022), and Agrawal et al., (2023) found that steep discounting was associated with a lower likelihood of social distancing and that experimental stressors led to steeper delay discounting. However, it is not well known if and how psychological distress may affect intertemporal and risky decision-making. This is unfortunate because psychological distress has increased in the recent decade and is now at a historically high levels (Hale et al., 2023). In an attempt to explain the relations among aging, decision-making, and psychological distress, Wan et al. (*under review*) proposed a *buffering hypothesis*. According to the buffering hypothesis, although

scarcity is a stressor that leads to steeper discounting, age-related improvements in emotional stability may buffer older adults against distress so that their discounting would then not be as steep as it may have been when they were younger and less emotionally stable. Therefore, in addition to examining the effect of age on discounting, the present study investigated the effect of psychological distress on decision-making and evaluated whether the buffering hypothesis could be generalized to decisions involving delayed and probabilistic outcomes, and if scarcity affected younger adults with lower incomes but not older adults with lower incomes because of their greater emotional stability.

Chapter 2: Method

2.1. Participants

Participants in each of the following four experiments were recruited from the pool maintained by Eyes4Research. For each experiment, the goal was for 100 participants, with equal representation of males and females, from each of the six age decades: 20-29, 30-39, 40-49, 50-59, 60-69, and 70-79 years of age.

2.1.1. Discounting of Delayed Gains

A sample of 874 participants was recruited. Of these, 13 participants did not report their ages on the demographics questionnaire or did not belong to the reported age groups (determined by concordance between responses on the demographics questionnaire and Eyes4Research request) and were excluded from subsequent analyses. In addition, 257 participants failed at least one of the six attention checks that were presented during the discounting procedure (e.g., "Please choose Lion", and the choice options were "Lion" and "Elephant"; "Which would you prefer to receive? $75 Now or $150 Now) and were not included in any subsequent analyses. Eight participants selected "non-binary" in response to a question regarding gender, and because the present study compared female and male participants, their data were not included in subsequent analyses, which as a result were based on a sample of 596 participants (see Table 2.1 for the demographic data for all four experiments).

Table 2.1 Demographics of participants in each of the four experiments.

		Delayed Gains	Delayed Losses	Probabilistic Gains	Probabilistic Losses
N		596	594	592	598
Age	Mean	49.693	49.926	50.647	50.236
	SD	17.199	16.986	17.246	16.995
Anxiety	Mean	8.428	8.073	7.915	8.059

(0-21)	SD	5.028	4.827	4.822	4.817
Depression	Mean	6.029	5.499	5.547	5.710
(0-21)	SD	3.986	3.865	3.996	4.034
Female	Perc	50.3%	50.2%	49.0%	50.3%
	N	300	298	290	301
Health	Mean	3.232	3.268	3.239	3.189
(1-5)	SD	1.024	0.993	1.033	1.011
College or	%	40.6	45.0	45.6	43.8
Above	N	241	266	269	259
Hispanic or	%	9.1	7.3	8.3	8.8
Latino	N	54	43	49	52
White	%	81.6	79.4	75.3	79.2
	N	485	470	446	473

Note. Due to missing responses, numbers and percentages do not always correspond to the total number in each experiment.

2.1.2. Discounting of Delayed Losses

A sample of 752 participants was recruited. Of these, 21 participants did not report their ages on the demographics questionnaire or did not belong to the reported age groups; of the remaining 731, 132 participants failed at least one of the six attention checks that were presented during the discounting part of the study; of the remaining 599, 5 participants selected “non-binary” in response to a question regarding gender. The subsequent analyses thus were based on a sample of 594 participants.

2.1.3. Discounting of Probabilistic Gains

A sample of 679 participants was recruited. Of these, 15 did not report their ages on the demographics questionnaire or did not belong to the reported age groups; of the remaining 664, 69 participants failed at least one of the six attention checks that were presented during the discounting part of the study; of the remaining 595, 3 participants selected “non-binary” in

response to a question regarding gender. The subsequent analyses thus were based on a sample of 592 participants.

2.1.4. Discounting of Probabilistic Losses

A sample of 963 participants was recruited. Of these, 40 participants did not report their ages on the demographics questionnaire or did not belong to the reported age groups; of the remaining 923, 322 participants failed at least one of the six attention checks that were presented during the discounting part of the study; of the remaining 601, 3 participants selected "non-binary" in response to a question regarding gender. The subsequent analyses thus were based on a sample of 598 participants.

2.2. Procedure

After agreeing to participate in the study, participants completed the adjusting-amount procedure (Du et al., 2002), which asked participants to make a series of choices between an immediate/certain, smaller outcome and a delayed/probabilistic, larger outcome. After completing the discounting procedure, participants were asked to complete the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) and a series of demographic questions.

The adjusting-amount discounting procedure consisted of three amount conditions, within each of which participants made a series of six choices between an immediate/certain, smaller outcome whose amount was adjusted based on a participant's previous choice, and a delayed/probabilistic, larger outcome whose amount remained constant within a condition. In the Delayed Gains and Probabilistic Gains experiments, if the participant chose the immediate/certain, smaller reward, the amount of the smaller reward was decreased on the following trial, whereas if the participant chose the delayed/probabilistic, larger reward, the amount of the immediate/certain reward was increased on the next trial. In the Delayed Losses

and Probabilistic Losses experiments, if the participant chose the immediate/certain, smaller payment, its amount was increased on the next trial, whereas if the participant chose the delayed/probabilistic, larger payment, the amount of the immediate/certain loss amount was decreased on the next trial. The first choice in each condition was between the delayed/probabilistic outcome and an immediate outcome whose amount was half that of the delayed/probabilistic outcome, and the first adjustment was half of the difference between the amounts of immediate/certain and delayed/probabilistic outcomes; the size of subsequent adjustments was half that of the previous adjustment.

The adjusting-amount procedure converges on an amount of immediate/certain outcome that approximates the subjective value of the delayed/probabilistic outcome. The amount of the immediate/certain outcome that would have been presented on an additional (seventh) choice trial, if one had been presented, provided an estimate of the subjective value of the delayed/probabilistic outcome. Within each amount condition, the procedure was repeated at different delays/probabilities to map out a discounting function reflecting the change in the subjective value of the reward as a function of its delay/probability.

For each experiment, there were three amounts of delayed/probabilistic outcomes: $150 (small), $2,500 (medium), and $30,000 (large). Each amount was studied at five delays (1 month, 3 months, 1 year, 3 years, and 10 years) in the discounting of delayed outcomes, and five probabilities (5%, 20%, 50%, 80%, 95%) in the discounting of probabilistic outcomes. The orders of presentation of the three amounts and the order of the delays/probabilities within each amount condition were randomly determined for each participant.

2.3. Measure

Annual household income was measured by asking participants to report their annual household income under five income categories: under $30K, between $30K and $50K, between $50K and $80K, between $80K and $100K, and above $100K. Because of the relatively small number of participants in the income groups of $80K-$100K and above $100K, participants from these two income groups were combined in the following data analyses.

Anxiety and *depression* were assessed using the Hospital Anxiety and Depression Scale (HADS), consisting of seven questions each for anxiety and depression. The scores for anxiety and depression each ranged from 0 to 21.

The level of *education* was measured by asking participants to report their education under five categories: some grade school, graduated from high school or completed a GED, some college, graduated from college, and any post-graduate or professional school. In the following analyses, participants were categorized into two education groups: below college (0; including some grade school, graduated from high school or completed a GED, and some college) and college or more (1; including graduated from college and any post-graduate or professional school).

Health was assessed with a single-item question that asked participants to rate their overall health ("At the present time, my overall health is?") under five categories: excellent, very good, good, fair, and poor. To facilitate the following analyses, the five-item was quantified into a 5-point scale with "excellent" being the highest score of 5 and "poor" being the lowest score of 1.

Three discounting *amounts* (i.e., $150, $2,500, and $30,000) were used in the present study. The logarithm of amount was used in the following analyses because of the large range of amounts.

Other demographic variables included in the following analyses were *the area under the curve* (*AuC*) (see Analysis), *age*, and *gender* (male=0; female=1). All independent variables were centered at the grand-mean for regression analyses.

2.4. Analysis

At the group level, the mean relative subjective values (i.e., subjective value as a proportion of the actual amount of the delayed/probabilistic outcome) for the delayed/probabilistic outcomes at each delay/odds-against (*odds against* = (1 – *probability*)/*probability*) for each amount were modeled with the hyperboloid discounting function (Eq. 1) in each experiment. At the individual level, discounting was measured as the area under the empirical discounting curve (AuC; Myerson et al., 2001) that was calculated for each amount in each experiment.

Four regression analyses were conducted. The first regression analysis examined the effect of age, the second examined the curvilinear effects of age via including the quadratic term of age. The third examined the effects of age, anxiety, and depression on the discounting measure (i.e., AuC), with statistical controls for health, gender, and amount. The fourth examined whether the age effect was moderated by age, anxiety, depression, health, gender, and amount via including all two-way interactions.

To test if there was a difference in the effect of age across income groups as predicted by the buffering hypothesis, two sets of focused contrasts were conducted. The first did not statistically control anxiety, depression, education, health, gender, and amount, whereas the second did. Each set of focused contrasts examined the effect of age on discounting at each income level. Only participants who were 35 years of age or older were included in these analyses because it is not obvious how one should interpret the incomes of either college students or young adults living at home. The focused contrast approach controlled for the lack of

power for detecting ordinal interactions using the traditional ANOVA-like approach (Furr & Rosenthal, 2003; Rosenthal & Rosnow, 1985; Strube & Bobko, 1989).

The regression analyses were conducted using beta regression because the AuC is continuous and restricted to the interval between 0 and 1 (Douma & Weedon, 2019). Multilevel analyses were used to account for the multiple amount conditions within individuals (i.e., three observations for each individual). The prior for each coefficient is a weakly informative default prior, following a Cauchy distribution with a location of 0 and a scale of 2.5 (Gelman et al., 2008). The priors for intercept and precision parameters and variance parameters follow a flat prior (i.e., Cauchy(0, 100^2)).

We examined the effect of age on the parameters of the hyperboloid discounting function (*b* and *s*; Eq. 1) by conducting two sets of nonlinear multilevel modeling of the indifference point at each delay/odds-against obtained from the adjusting-amount procedure. The first set did not control for anxiety, depression, health, gender, and amount at Level 2, and the second set did. In order to reduce the skewness of discounting parameters of the hyperboloid discounting model, *b* and *s*, and normalize the distribution of residuals at Level 2, parameters *b* and *s* were both log-transformed via being exponentiated before being fitted to the data (i.e., $V = A/(1 + \exp(b)X)^{\exp(s)}$).

The variance at Level 1 was assumed to follow a Gaussian distribution.[1] The prior for the intercept of discounting parameters *b* follows a Cauchy distribution with a location of 0 and a scale of 5, and the prior for the intercept of discounting parameters *s* follows a flat prior. The

[1] Beta regression was attempted, but the models failed to converge using both frequentist and Bayesian approaches.

prior for each coefficient follows a Cauchy distribution with a location of 0 and a scale of 2.5. The prior for Level 1's variance follows an exponential distribution with a rate of 1, and the prior for Level 2's variance follows an exponential distribution with a rate of 0.05.

Major analyses were conducted using R Version 4.2.1 (R Core Team, 2022) and Stan (Carpenter et al., 2017). The CmdStanR (Gabry & Češnovar, 2022) and brms (Bürkner, 2017) software packages were used to conduct Bayesian regression analyses. 10 chains for 10000 iterations were generated. The final 5000 iterations of each chain converged as indicated by post-modeling diagnostics and were used to compute posterior estimates. Inferences in the following section were reported using posterior median and 95% credible interval.

Chapter 3: Results

3.1. Discounting of Delayed Outcomes

Figure 3.1 depicts the mean relative subjective (present) values at each amount of the delayed rewards (top panels) and the delayed losses (bottom panels) as a function of delay for each of the six age decades. Relative subjective value decreased systematically as a function of delay in all three amount conditions. In each case, the hyperboloid discounting function (Myerson & Green, 1995) provided good fits to the group data at each amount. Across the fits to the data from the three delayed gains amounts, all R^2s were above 93%, and across the fits to the data from the three delayed losses amounts, all R^2s were above 85%.

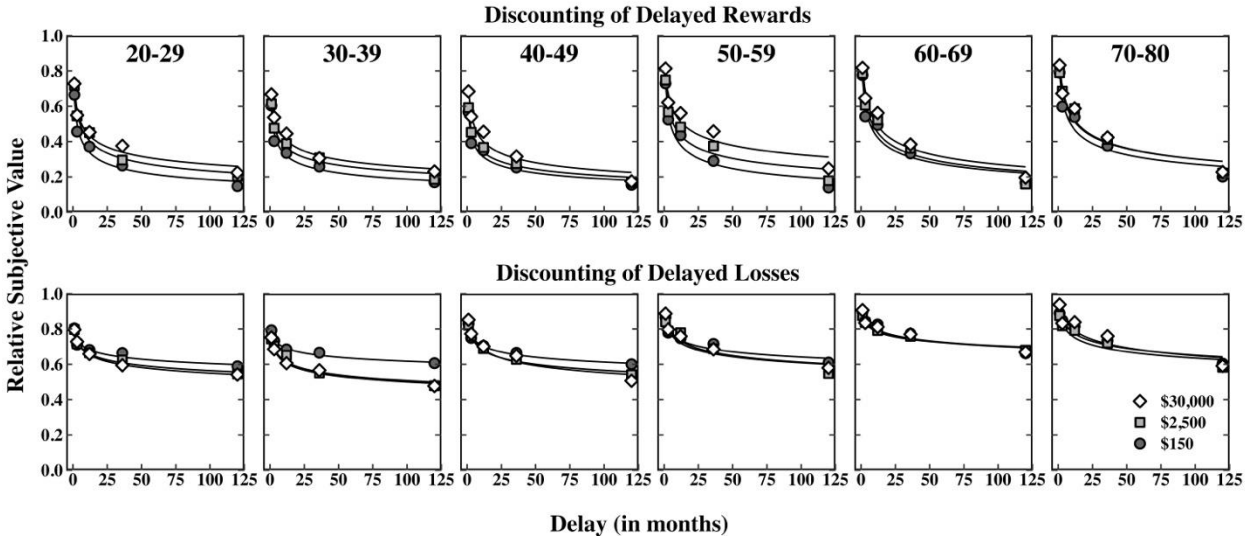

Figure 3.1 Relative subjective value of the reward (top panels) and payment (bottom panels) as a function of delay for each age decade. Data represent the group means, and curves represent the best-fitting hyperboloid discounting functions.

A clear magnitude effect was observed for the discounting of delayed rewards: Larger delayed amounts were discounted less steeply than smaller delayed amounts. Linear contrasts based on

the beta regression revealed a systematic increase in AuC, indicating successively shallower discounting, as the amount of the delayed reward increased ($p < .001$). There was no apparent magnitude effect for the discounting of delayed losses, though linear contrasts based on the beta regression revealed a decrease in AuC as a function of the amount ($p = .034$).

Table 3.1 shows the intercorrelations among the discounting measure (AuC) and other variables in each of the two delay discounting experiments. As may be seen, a significant correlation between age and discounting was observed for both delayed gains and delayed losses: older participants were more likely to choose the larger, later reward and the smaller, sooner payment than younger participants. In addition, there were significant correlations between age and anxiety as well as between age and depression such that anxiety and depression decreased with age.

Table 3.1 Correlations among the discounting measures and other variables in the experiments of discounting of delayed outcomes.

A. Correlations in the discounting of delayed gains.

	AuC	Age	Anxiety	Depression	Gender	Health
Age	0.182***	-				
Anxiety	-0.093*	-0.396***	-			
Depression	-0.064	-0.201***	0.650***	-		
Gender	0.027	0.008	0.100*	0.032	-	
Health	0.058	-0.136***	-0.191***	-0.430***	-0.169***	-
Education	0.058	0.004	-0.054	-0.055	-0.164***	0.171***

B. Correlations in the discounting of delayed losses.

	AuC	Age	Anxiety	Depression	Gender	Health
Age	0.227***	-				
Anxiety	-0.188***	-0.338***	-			
Depression	-0.090*	-0.180***	0.650***	-		
Gender	-0.056	-0.002	0.132**	0.035	-	

Health	0.090*	-0.081*	-0.347***	-0.498***	-0.023	-
Education	0.082*	-0.023	-0.110**	-0.152***	-0.052	0.193***

Note. * $p < .05$. ** $p < .01$. *** $p < .001$

Four sets of regression analyses were conducted using multilevel generalized linear models to examine the effect of age, the curvilinear effect of age, and a moderation effect with age. Consistent with the correlations reported in Table 3.1, analysis revealed a significant effect of age in the discounting of both types of delayed outcomes. More specifically, older participants were more likely to choose the larger, later reward and the smaller, sooner payment than younger participants (see Table 3.2). To examine the curvilinear effect of age, a quadratic term of age was added into the model. The quadratic effect of age reached statistical significance for the discounting of delayed rewards but not for delayed losses: older participants were more likely to choose the larger, later reward than younger participants, and such age-related differences increased with age.

Table 3.2 Model estimates obtained from Bayesian regression that regressed discounting on age and other variables in each delay discounting experiment.

A. Regression of AuC in the discounting of delayed gains.

	Delayed Gains			
	Model 1	Model 2	Model 3	Model 4
Intercept	-0.968	-1.100	-1.099	-1.083
	[-1.070,-0.866]	[-1.251,-0.942]	[-1.257,-0.944]	[-1.253,-0.911]
Age	0.348	0.360	0.420	0.426
	[0.155,0.556]	[0.164,0.556]	[0.193,0.652]	[0.201,0.670]
Age2		0.530	0.472	0.458
		[0.068,0.997]	[-0.007,0.939]	[-0.043,0.981]
Anxiety			0.027	0.034
			[-0.275,0.313]	[-0.265,0.347]
Depression			0.072	0.031
			[-0.231,0.374]	[-0.277,0.360]

Gender			0.081	0.111
			[-0.125,0.295]	[-0.106,0.325]
Health			0.303	0.254
			[0.058,0.539]	[0.002,0.504]
Amount			0.313	0.316
			[0.247,0.381]	[0.250,0.384]
Age:Anxiety				-0.007
				[-0.640,0.655]
Age:Depression				0.098
				[-0.554,0.755]
Age:Gender				-0.203
				[-0.662,0.288]
Age:Health				-0.069
				[-0.594,0.458]
Age:Amount				-0.172
				[-0.316,-0.022]
Anxiety:Depression				-0.066
				[-0.582,0.432]
Anxiety:Gender				-0.407
				[-0.996,0.202]
Anxiety:Health				0.462
				[-0.167,1.093]
Anxiety:Amount				-0.154
				[-0.342,0.045]
Depression:Gender				0.530
				[-0.059,1.169]
Depression:Health				-0.374
				[-0.917,0.162]
Depression:Amount				0.027
				[-0.171,0.223]
Gender:Health				0.318
				[-0.185,0.793]
Gender:Amount				0.064
				[-0.071,0.199]
Health:Amount				0.089
				[-0.064,0.243]
N	596	596	585	585
Information Criteria				
WAIC	-2597.261	-2597.337	-2666.924	-2668.664
LOO	-2521.849	-2522.552	-2591.770	-2586.576

B. Regression of AuC in the discounting of delayed losses.

	Delayed Losses			
	Model 1	Model 2	Model 3	Model 4
Intercept	0.764	0.736	0.769	0.757
	[0.661,0.860]	[0.581,0.888]	[0.672,0.872]	[0.629,0.888]
Age	0.419	0.419	0.372	0.386
	[0.220,0.612]	[0.222,0.612]	[0.158,0.588]	[0.159,0.604]
Age2		0.118		
		[-0.351,0.585]		
Anxiety			-0.417	-0.376
			[-0.700,-0.145]	[-0.658,-0.081]
Depression			0.300	0.243
			[0.020,0.587]	[-0.062,0.555]
Gender			-0.054	-0.053
			[-0.252,0.146]	[-0.251,0.153]
Health			0.243	0.266
			[0.004,0.472]	[0.020,0.503]
Amount			-0.190	-0.190
			[-0.272,-0.115]	[-0.267,-0.110]
Age:Anxiety				0.021
				[-0.568,0.567]
Age:Depression				-0.136
				[-0.737,0.476]
Age:Gender				0.028
				[-0.418,0.450]
Age:Health				0.011
				[-0.500,0.521]
Age:Amount				0.302
				[0.132,0.474]
Anxiety:Depression				-0.077
				[-0.568,0.425]
Anxiety:Gender				0.174
				[-0.367,0.734]
Anxiety:Health				0.369
				[-0.226,0.980]
Anxiety:Amount				0.185
				[-0.036,0.404]
Depression:Gender				-0.398
				[-0.981,0.182]

Depression:Health				-0.428 [-0.945,0.108]
Depression:Amount				-0.112 [-0.341,0.110]
Gender:Health				-0.297 [-0.755,0.188]
Gender:Amount				-0.229 [-0.380,-0.067]
Health:Amount				-0.013 [-0.203,0.169]
N	594	594	585	585
Information Criteria				
WAIC	-1887.628	-1888.995	-1907.822	-1928.614
LOO	-1827.168	-1826.404	-1844.302	-1861.337

Two additional regression analyses were conducted to examine the effects of anxiety and depression and whether the age effect was moderated by gender, health, and/or amount. Because of the significant quadratic effect of age in the discounting of delayed rewards, the quadratic term of age remained in the analyses for the discounting of delayed rewards. Consistent with the previous analyses, the age effect remained significant for the discounting of both types of delayed outcomes, with other variables statistically controlled (see Figure 3.2). However, the quadratic effect of age failed to remain significant in the discounting of delayed rewards with other variables statistically controlled. For the discounting of delayed gains, neither the effects of anxiety nor depression were significant. A significant effect of health was observed: adults in better health were more likely to choose larger, later rewards than adults in poorer health. In contrast to the results with delayed rewards, analysis revealed significant effects of anxiety and depression for the discounting of delayed losses: participants with higher anxiety were more likely to choose the larger, later payment than participants with lower anxiety, while participants with higher depression were more likely to choose the smaller, sooner payment than participants

with lower depression. There was a significant effect of health on the discounting of delayed losses as well: adults in better health condition were more likely to choose smaller, sooner payments than adults in poorer health condition.

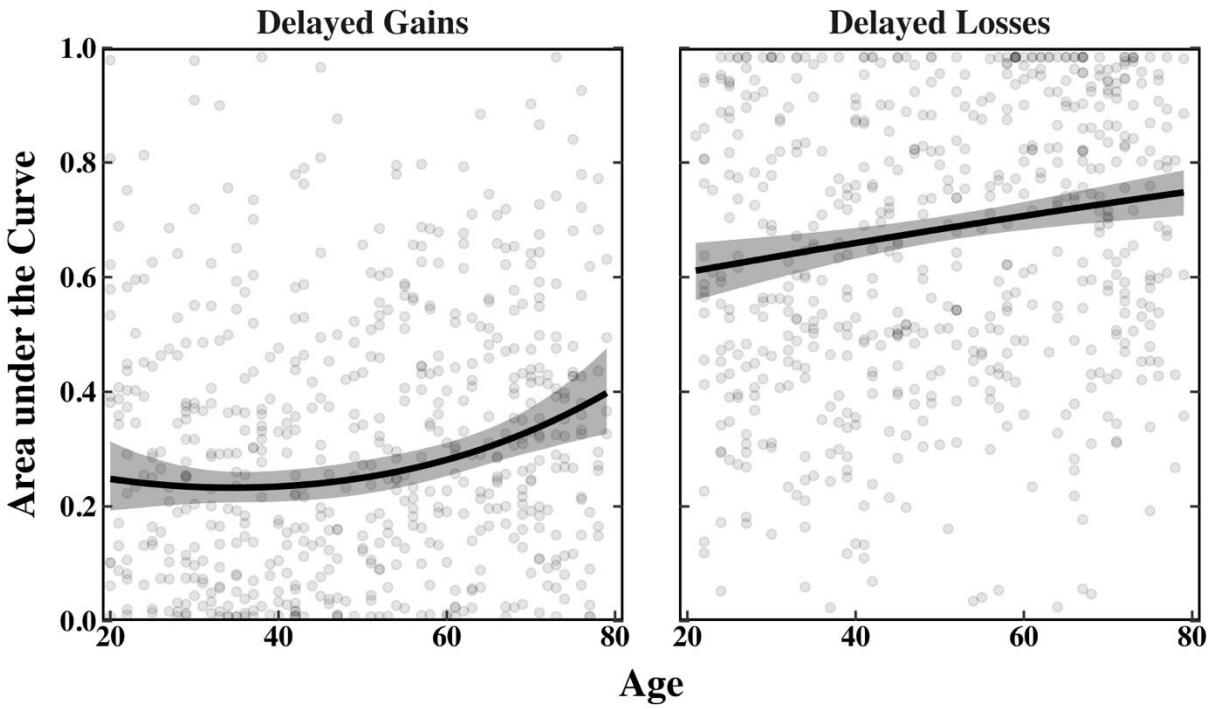

Figure 3.2 Estimated area under the curve as a function of age with anxiety, depression, gender, health, and amount statistically controlled (Model 3) in the experiments of discounting of delayed gains (left) and delayed losses (right). The black line represents the estimated mean of the area under the curve across age, with shading depicting the 95% credible interval of that mean. The gray dots represent the mean of the area under the curve from each participant.

In order to examine the moderation effect of other variables with age, all possible two-way interactions were added into the regression model. For the discounting of both delayed gains and delayed losses, analysis revealed a significant moderation effect of amount with age but the

effect was in opposite directions for gains and losses. More specifically, with respect to the discounting of delayed rewards, although posterior distribution analysis revealed a significant effect of age at each amount, the age effect leveled off with amount. With respect to the discounting of delayed losses, posterior distribution analysis revealed that there was no significant age effect with the small amount, while significant effects of age were observed with the middle and large amounts, with the largest age effect with the largest amount. There were no significant moderation effects of other variables with age.

Two sets of focused contrasts were conducted using multilevel generalized linear models to examine the effect of age at each level of income for each delayed outcome. The first set did not statistically control for anxiety, depression, education, health, gender, and amount, whereas the second did. Analysis for the first set revealed that when the delayed outcome was a reward, there was a significant effect of age for the lower income group (i.e., <$30K): older participants with lower incomes were more likely to choose the larger, later reward than younger participants with lower incomes (see Table 3.3 and Figure 3.3 [top panels]). No significant age effect was observed for the other income groups. In contrast, when the delayed outcome was a loss, analyses revealed the opposite pattern: no significant age effect for the lower income group (<$30K), while there was a significant age effect for the other income groups. More specifically, older participants with higher incomes were more likely to choose the smaller, sooner payment than younger participants with higher incomes (Figure 3.3 [bottom panels]).

Table 3.3 Model estimates obtained from Bayesian regression that regressed discounting on age and other variables at each level of income in each delay discounting experiments.

A. Regression of AuC in the discounting of delayed gains at each level of income.

	Delayed Gains							
	<$30k		*$30k-50k*		*$50k-80k*		*>$80k*	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Intercept	-1.382	-1.371	-0.860	-0.856	-0.832	-0.862	-0.364	-0.398
	[-1.609,-1.164]	[-1.597,-1.149]	[-1.085,-0.630]	[-1.089,-0.617]	[-1.077,-0.583]	[-1.104,-0.610]	[-0.605,-0.138]	[-0.640,-0.157]
Age	0.634	0.664	0.264	0.258	0.307	0.462	0.428	0.362
	[0.204,1.065]	[0.198,1.119]	[-0.185,0.708]	[-0.247,0.753]	[-0.172,0.805]	[-0.205,1.103]	[-0.046,0.877]	[-0.160,0.883]
Anxiety		0.156		0.058		-0.569		-0.144
		[-0.477,0.793]		[-0.547,0.638]		[-1.509,0.323]		[-0.867,0.604]
Depression		0.084		0.025		1.101		-0.190
		[-0.588,0.728]		[-0.571,0.609]		[0.242,1.974]		[-0.973,0.567]
Education		0.070		-0.047		0.026		-0.083
		[-0.373,0.515]		[-0.509,0.406]		[-0.486,0.524]		[-0.578,0.467]
Gender		0.140		0.240		0.260		-0.001
		[-0.358,0.594]		[-0.245,0.686]		[-0.276,0.784]		[-0.523,0.526]
Health		0.121		0.365		0.428		0.006
		[-0.402,0.637]		[-0.138,0.835]		[-0.176,1.062]		[-0.560,0.548]
Amount		0.301		0.282		0.338		0.497
		[0.175,0.427]		[0.142,0.426]		[0.201,0.477]		[0.323,0.657]
N	133	131	101	100	99	97	94	93
Information Criteria								
WAIC	-791.117	-786.282	-431.685	-440.507	-461.309	-483.020	-260.098	-300.054
LOO	-773.801	-766.533	-417.015	-424.495	-448.403	-468.231	-249.169	-286.578

B. Regression of AuC in the discounting of delayed losses at each level of income.

	Delayed Losses							
	<$30k		*$30k-50k*		*$50k-80k*		*>$80k*	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Intercept	0.581	0.562	1.028	1.019	0.912	0.944	0.990	1.017
	[0.351,0.815]	[0.334,0.795]	[0.773,1.279]	[0.754,1.274]	[0.671,1.145]	[0.716,1.177]	[0.787,1.209]	[0.784,1.234]
Age	0.225	0.023	0.775	0.873	0.541	0.455	0.510	0.515
	[-0.246,0.673]	[-0.461,0.534]	[0.265,1.291]	[0.303,1.448]	[0.064,0.987]	[-0.033,0.936]	[0.103,0.922]	[0.024,1.008]
Anxiety		-0.775		-0.126		-0.259		0.124
		[-1.390,-0.133]		[-0.899,0.643]		[-0.914,0.419]		[-0.505,0.736]
Depression		0.369		0.524		-0.155		-0.191
		[-0.286,1.039]		[-0.275,1.265]		[-0.817,0.527]		[-0.826,0.423]
Education		0.041		-0.350		-0.009		0.069
		[-0.420,0.511]		[-0.889,0.186]		[-0.490,0.477]		[-0.397,0.539]
Gender		0.043		-0.142		0.066		-0.184
		[-0.433,0.525]		[-0.691,0.386]		[-0.438,0.543]		[-0.645,0.295]
Health		0.032		0.037		0.328		0.013
		[-0.529,0.579]		[-0.583,0.666]		[-0.227,0.869]		[-0.485,0.514]
Amount		-0.131		-0.176		-0.240		-0.019
		[-0.287,0.026]		[-0.363,0.012]		[-0.440,-0.051]		[-0.204,0.160]
N	134	132	96	95	102	101	103	99
Information Criteria								
WAIC	-440.292	-433.808	-404.903	-396.772	-342.797	-347.793	-359.802	-354.184
LOO	-424.574	-416.680	-392.636	-383.749	-333.265	-334.599	-349.726	-342.374

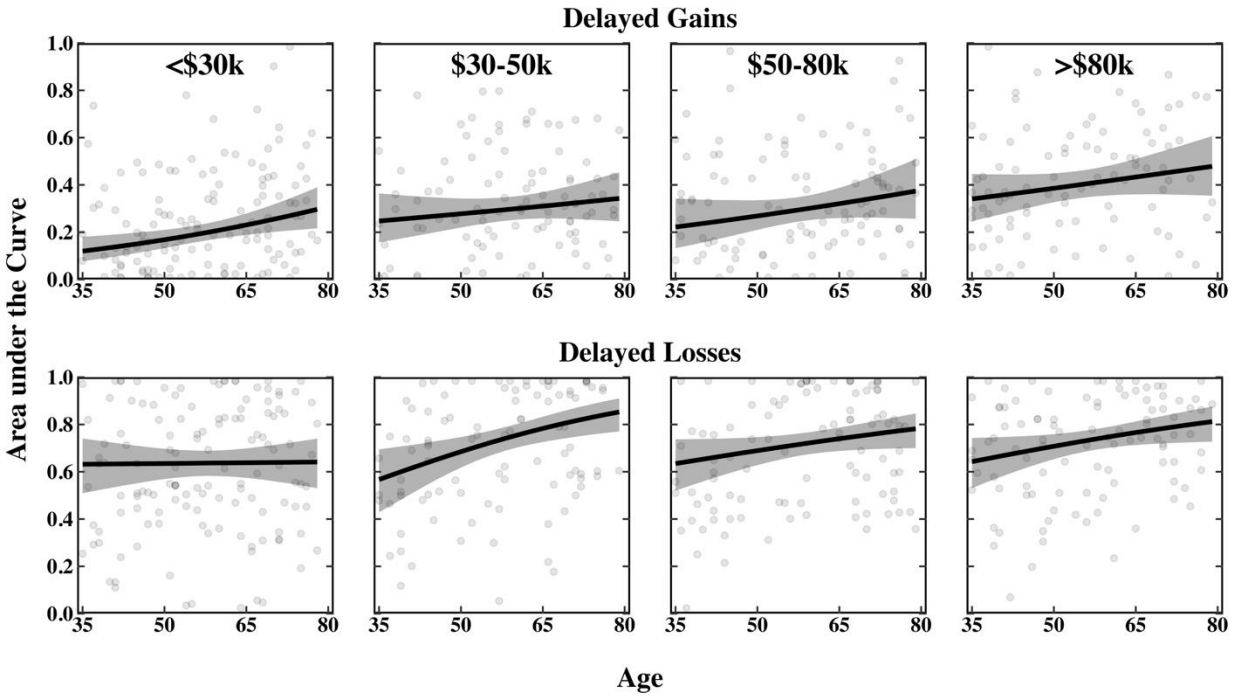

Figure 3.3 Estimated area under the curve as a function of age with anxiety, depression, gender, education, health, and amount statistically controlled at each income level in the experiments of discounting of delayed gains (top panels) and delayed losses (bottom panels). The black line represents the estimated mean of area under the curve across ages, with shading depicting the 95% credible interval of that mean. The gray dots represent the mean of the area under the curve from each participant.

The second set of focused contrasts was conducted to examine the effect of age with anxiety, depression, education, health, gender, and amounts statistically controlled. For the discounting of delayed rewards, while the effect of age was still non-significant for the three higher-income groups, the age effect remained significant for participants with low incomes: older participants with lower incomes chose later, larger rewards more often than younger participants with lower incomes. For the discounting of delayed losses, the age effect remained insignificant for the

lowest income group while it remained significant for two of the other three income groups, but not the income group of $50K-$80K, although it should be noted that the *probability of direction*[2] for this income group was .963.

Two sets of nonlinear multilevel models were conducted to examine the effect of age on the parameters of the hyperboloid discounting function for the discounting of delayed outcomes. The first did not statistically control for anxiety, depression, education, health, gender, and amount, and the second one did. The first nonlinear multilevel model revealed a significant age effect on both discounting parameters of *b* and *s* for the discounting of both types of delayed outcomes. More specifically, the estimated logarithmic value of *b* decreased while the estimated logarithmic value of *s* increased as a function of age in the discounting of delayed gains and losses (see Table 3.4). With anxiety, depression, education, health, gender, and amount statistically controlled, for the discounting of both types of delayed outcomes, while the age effect on the parameter *s* failed to remain significant, the effect of age on the parameter *b* remained significant. Figure 3.4 shows the effect of age on the estimated hyperboloid discounting function obtained from the nonlinear multilevel model for delayed gains (left panel) and delayed losses (right panel) with other variables statistically controlled.

[2] *Probability of direction* is the proportion of the posterior distribution that is in the same direction as the parameter estimate and is an indicator of certainty about the direction of the effect being estimated.

Table 3.4 Model estimates obtained from Bayesian nonlinear analyses that examined the effects of age and other variables on the parameters of the hyperboloid discounting function in the discounting of delayed outcomes.

	Delayed Gains		Delayed Losses	
	Model 1	Model 2	Model 1	Model 2
b:Intercept	-0.382	-0.421	-0.065	-0.039
	[-0.580,-0.170]	[-0.642,-0.197]	[-0.524,0.390]	[-0.470,0.399]
b:Age	-1.317	-0.794	-3.010	-2.458
	[-1.714,-0.899]	[-1.258,-0.317]	[-3.799,-2.231]	[-3.322,-1.690]
b:Anxiety		1.100		0.084
		[0.497,1.706]		[-0.861,1.084]
b:Depression		-0.569		0.291
		[-1.184,0.031]		[-0.705,1.345]
b:Gender		-0.541		0.778
		[-0.977,-0.114]		[0.072,1.511]
b:Health		-0.322		-0.354
		[-0.827,0.163]		[-1.215,0.467]
b:Amount		-1.630		-3.807
		[-1.856,-1.410]		[-4.089,-3.539]
s:Intercept	-0.773	-0.721	-2.182	-2.132
	[-0.852,-0.692]	[-0.800,-0.639]	[-2.326,-2.040]	[-2.269,-1.992]
s:Age	0.201	-0.063	0.375	0.209
	[0.047,0.363]	[-0.229,0.102]	[0.151,0.606]	[-0.033,0.465]
s:Anxiety		-0.423		0.357
		[-0.625,-0.209]		[0.052,0.679]
s:Depression		0.184		-0.350
		[-0.036,0.393]		[-0.681,-0.028]
s:Gender		0.135		-0.089
		[-0.013,0.289]		[-0.307,0.145]
s:Health		-0.050		-0.167
		[-0.215,0.126]		[-0.433,0.105]
s:Amount		0.424		1.190
		[0.323,0.521]		[1.107,1.275]
N	596	585	594	585
Information Criteria				
WAIC	-3089.560	-3620.025	-3657.497	-4554.528
LOO	-3067.188	-3589.327	-3635.668	-4500.924

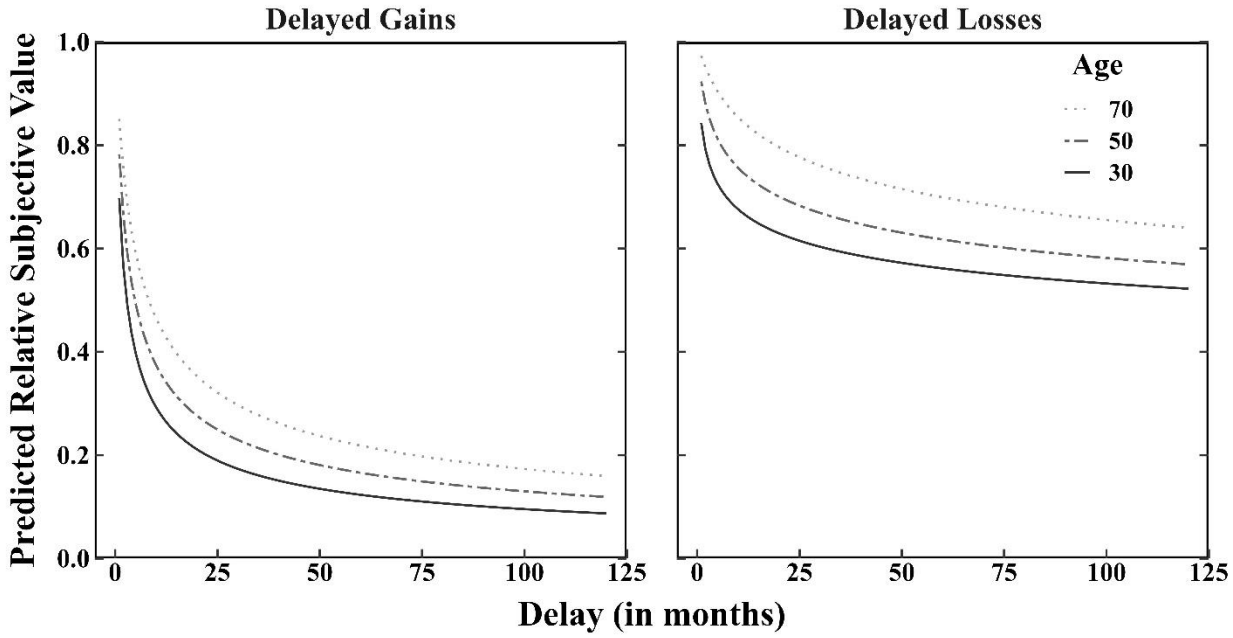

Figure 3.4 Estimated relative subjective value of the delayed reward (left) and delayed payment (right) as a function of the delay at each age category based on the hyperboloid discounting function with anxiety, depression, gender, health, and amount statistically controlled. The lines represent the estimated mean of relative subjective value for each age across delays.

3.2. Discounting of Probabilistic Outcomes

Figure 3.5 depicts the mean relative subjective values of the probabilistic reward (top panels) and the probabilistic losses (bottom panels) as a function of their odds against for each of the six age decades. Relative subjective value decreased systematically as a function of odds against in all three amount conditions. In each case, the hyperboloid discounting function provided good fits to the group data at each amount. Across the fits to the data from the three probabilistic gains amounts, all R^2s were above 96%, and across the fits to the data from the three probabilistic losses amounts, all R^2s were above 89%.

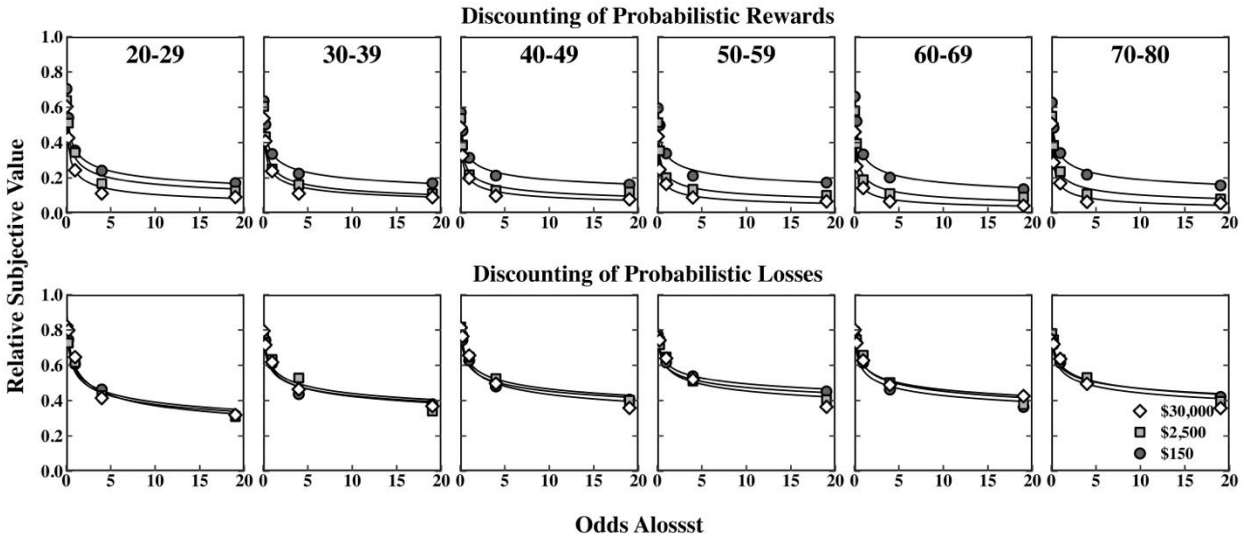

Figure 3.5 Relative subjective values of the reward (top panels) and the payment (bottom panels) as a function of the odds against for each age decade. Data represent the group means, and curves represent the best-fitting hyperboloid discounting functions.

Similar to the discounting of delayed outcomes, a clear magnitude effect was observed for the discounting of probabilistic rewards but not for probabilistic losses: Larger probabilistic rewards were discounted more steeply than smaller probabilistic rewards. This was verified statistically: When the probabilistic outcome was a reward, linear contrasts based on the beta regression revealed a systematic decrease in AuC, indicating successively steeper discounting as the probabilistic reward amount increased ($p < .001$). In contrast, when the probabilistic outcome was a loss, no magnitude effect was observed ($p = .600$).

Table 3.5 shows the intercorrelations among the discounting measure and other variables in each of the probability discounting experiments. A significant correlation between age and discounting was observed for the discounting of probabilistic rewards but not for the probabilistic losses. Older participants were more likely to choose the smaller, certain reward

than younger participants. Consistent with those in the two experiments of delayed outcomes, there were significant correlations between age and anxiety as well as between age and depression such that anxiety and depression decreased with age.

Table 3.5 Correlations among the discounting measure and other variables in the experiments of discounting of probabilistic outcomes.

A. Correlations in the discounting of probabilistic gains.

	AuC	Age	Anxiety	Depression	Gender	Health
Age	-0.125**	-				
Anxiety	0.111**	-0.336***	-			
Depression	-0.012	-0.183***	0.630***	-		
Gender	-0.059	0.013	0.103*	-0.022	-	
Health	0.103*	-0.158***	-0.240***	-0.431***	-0.030	-
Education	0.017	0.016	-0.136***	-0.130**	-0.077	0.126**

B. Correlations in the discounting of probabilistic losses.

	AuC	Age	Anxiety	Depression	Gender	Health
Age	0.028	-				
Anxiety	-0.031	-0.365***	-			
Depression	-0.030	-0.172***	0.705***	-		
Gender	0.072	-0.013	0.105*	-0.048	-	
Health	-0.034	-0.079	-0.281***	-0.394***	-0.016	-
Education	-0.083*	0.024	-0.064	-0.120**	-0.016	0.137***

Note. * $p < .05$. ** $p < .01$. *** $p < .001$

Four sets of regression analyses were conducted using multilevel generalized linear models to examine the effect of age, the curvilinear effect of age, and a moderation effect with age. Without controlling other variables, analysis revealed a significant age effect in the discounting of probabilistic gains: older participants were more likely to choose the smaller, certain reward than younger participants. No age effect was observed in the discounting of probabilistic losses. The quadratic effect of age failed to reach significance in the discounting of both types of

probabilistic outcomes. With anxiety, depression, health, gender, and amount statistically controlled, however, analyses failed to reveal significant effects of age in the discounting of either type of probabilistic outcome (see Table 3.6 and Figure 3.6).

Table 3.6 Model estimates obtained from Bayesian regression that regressed discounting on age and other variables in each probability discounting experiment.

A. Regression of AuC in the discounting of probabilistic gains.

	Probabilistic Gains			
	Model 1	Model 2	Model 3	Model 4
Intercept	-1.913	-1.974	-2.015	-1.979
	[-2.002,-1.822]	[-2.111,-1.837]	[-2.107,-1.917]	[-2.106,-1.853]
Age	-0.204	-0.199	-0.009	-0.036
	[-0.386,-0.036]	[-0.373,-0.022]	[-0.213,0.190]	[-0.234,0.174]
Age2		0.246		
		[-0.167,0.638]		
Anxiety			0.502	0.473
			[0.259,0.752]	[0.216,0.731]
Depression			-0.225	-0.180
			[-0.481,0.035]	[-0.453,0.098]
Gender			-0.136	-0.122
			[-0.318,0.050]	[-0.303,0.071]
Health			0.291	0.304
			[0.069,0.495]	[0.085,0.520]
Amount			-0.820	-0.829
			[-0.886,-0.752]	[-0.896,-0.762]
Age:Anxiety				-0.307
				[-0.846,0.214]
Age:Depression				0.274
				[-0.310,0.850]
Age:Gender				-0.108
				[-0.521,0.293]
Age:Health				0.033
				[-0.423,0.482]
Age:Amount				-0.223
				[-0.365,-0.082]
Anxiety:Depression				-0.286

				[-0.734,0.172]
Anxiety:Gender				-0.252
				[-0.764,0.230]
Anxiety:Health				0.273
				[-0.205,0.761]
Anxiety:Amount				-0.012
				[-0.185,0.170]
Depression:Gender				0.278
				[-0.248,0.786]
Depression:Health				-0.146
				[-0.597,0.323]
Depression:Amount				-0.016
				[-0.204,0.172]
Gender:Health				0.055
				[-0.381,0.486]
Gender:Amount				-0.017
				[-0.149,0.116]
Health:Amount				0.119
				[-0.031,0.267]
N	592	592	586	586
Information Criteria				
WAIC	-4023.424	-4023.733	-4614.669	-4621.035
LOO	-3964.920	-3966.159	-4537.210	-4539.190

B. Regression of AuC in the discounting of probabilistic losses.

	Probabilistic Losses			
	Model 1	Model 2	Model 3	Model 4
Intercept	-0.124	-0.068	-0.139	-0.177
	[-0.212,-0.035]	[-0.203,0.066]	[-0.228,-0.050]	[-0.297,-0.063]
Age	0.150	0.149	0.154	0.128
	[-0.026,0.320]	[-0.033,0.326]	[-0.036,0.351]	[-0.068,0.332]
Age2		-0.224		
		[-0.632,0.186]		
Anxiety			0.014	-0.001
			[-0.246,0.297]	[-0.285,0.266]
Depression			-0.020	-0.095
			[-0.283,0.244]	[-0.373,0.174]
Gender			0.204	0.213

			[0.024,0.385]	[0.029,0.400]
Health			-0.063	-0.095
			[-0.251,0.136]	[-0.295,0.107]
Amount			-0.056	-0.055
			[-0.131,0.015]	[-0.126,0.018]
Age:Anxiety				0.153
				[-0.362,0.690]
Age:Depression				0.196
				[-0.351,0.736]
Age:Gender				0.171
				[-0.224,0.578]
Age:Health				-0.117
				[-0.565,0.298]
Age:Amount				-0.009
				[-0.174,0.144]
Anxiety:Depression				0.482
				[0.091,0.874]
Anxiety:Gender				-0.281
				[-0.829,0.266]
Anxiety:Health				0.285
				[-0.276,0.853]
Anxiety:Amount				-0.015
				[-0.239,0.208]
Depression:Gender				0.184
				[-0.367,0.722]
Depression:Health				-0.045
				[-0.560,0.472]
Depression:Amount				-0.074
				[-0.295,0.144]
Gender:Health				0.004
				[-0.413,0.386]
Gender:Amount				-0.038
				[-0.180,0.114]
Health:Amount				-0.082
				[-0.247,0.077]
N	598	598	583	583
Information Criteria				
WAIC	-1352.277	-1352.957	-1314.288	-1301.860
LOO	-1292.478	-1294.456	-1255.861	-1239.934

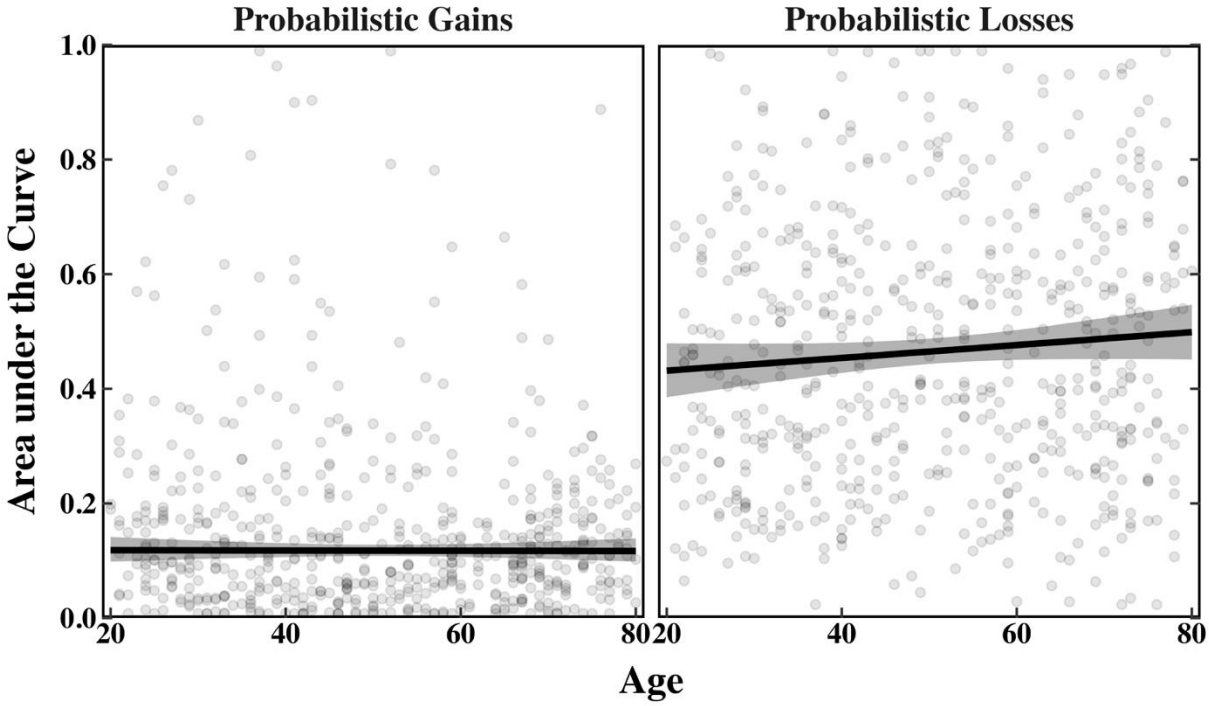

Figure 3.6 Estimated area under the curve as a function of age with anxiety, depression, gender, health, and amount statistically controlled (Model 3) in the experiments of discounting of probabilistic gains (left) and probabilistic losses (right). The black line represents the estimated mean of Area under the Curve across ages, with shading depicting the 95% credible interval of that mean. The gray dot represents the mean of the area under the curve from each participant.

In the third set of regression analysis where anxiety, depression, health, gender, and amount were statistically controlled, for probabilistic rewards a significant effect was observed for anxiety but not for depression: participants with higher anxiety were more likely to choose the larger, probabilistic reward than participants with lower anxiety. The effect of health was significant: adults in better health were more likely to choose the larger, probabilistic reward than participants in poorer health. For probabilistic losses, no significant effects of anxiety or

depression were observed. The effect of gender was significant: females choose the smaller, certain payment more often than males.

The fourth set of regression analysis was conducted for each probability discounting task to examine the moderation effect of other variables with age. With respect to the discounting of probabilistic rewards, analysis revealed a significant moderation effect of amount with age on discounting such that the age effect decreased as a function of amount, although the posterior distribution analysis failed to reveal a significant age effect at all three amounts. There was no other moderation effect with age. With respect to the discounting of probabilistic losses, there was no significant moderation effect of other variables with Age.

Two sets of focused contrasts were conducted using multilevel generalized linear models to examine the effect of age at each level of income for the discounting of probabilistic gains and the discounting of probabilistic losses. The first set did not statistically control for anxiety, depression, education, health, gender, and amount whereas the second did. In contrast to the discounting of delayed outcomes, analyses did not reveal a significant effect of age for each income group with or without other variables statistically controlled in both types of probability discounting tasks (see Table 3.7 and Figure 3.7). In the second set of focused contrasts where anxiety, depression, education, health, gender, and amount were statistically controlled, while depression failed to reach significance in all income groups, a significant effect of anxiety was observed for the $50K-$80K and >$80K income groups for probabilistic gains such that participants with higher anxiety were more likely to choose the larger, probabilistic reward than participants with lower anxiety. For probabilistic losses, neither anxiety nor depression was significant across income groups.

Table 3.7 Model estimates obtained from Bayesian regression that regressed discounting on age and other variables at each level of income in each probability discounting experiments.

A. Regression of AuC in the discounting of probabilistic gains at each level of income.

	Probabilistic Gains							
	<$30k		*$30k-50k*		*$50k-80k*		*>$80k*	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Intercept	-2.048	-2.147	-1.924	-2.034	-1.929	-2.084	-1.860	-1.952
	[-2.242,-1.854]	[-2.354,-1.950]	[-2.160,-1.685]	[-2.291,-1.782]	[-2.131,-1.732]	[-2.297,-1.870]	[-2.084,-1.631]	[-2.184,-1.726]
Age	0.108	0.178	-0.309	-0.225	-0.223	-0.079	-0.222	0.112
	[-0.247,0.491]	[-0.240,0.618]	[-0.732,0.146]	[-0.813,0.340]	[-0.609,0.141]	[-0.529,0.366]	[-0.651,0.233]	[-0.397,0.609]
Anxiety		0.111		0.312		0.651		0.861
		[-0.418,0.625]		[-0.403,0.997]		[0.053,1.203]		[0.274,1.444]
Depression		0.019		-0.129		-0.364		-0.557
		[-0.476,0.543]		[-0.806,0.502]		[-0.968,0.244]		[-1.248,0.136]
Education		-0.231		-0.098		-0.043		-0.173
		[-0.637,0.148]		[-0.623,0.395]		[-0.459,0.385]		[-0.651,0.304]
Gender		-0.207		0.165		-0.245		-0.683
		[-0.612,0.193]		[-0.373,0.699]		[-0.688,0.203]		[-1.183,-0.164]
Health		0.202		0.238		0.280		0.059
		[-0.225,0.629]		[-0.353,0.792]		[-0.163,0.747]		[-0.543,0.657]
Amount		-0.753		-0.917		-0.952		-0.848
		[-0.907,-0.594]		[-1.079,-0.761]		[-1.095,-0.805]		[-1.007,-0.696]
N	129	126	109	109	112	111	96	95
Information Criteria								
WAIC	-952.948	-1025.214	-754.817	-893.022	-746.861	-910.074	-626.972	-739.325
LOO	-940.635	-1008.027	-741.722	-873.134	-734.249	-890.529	-616.304	-724.102

B. Regression of AuC in the discounting of probabilistic losses at each level of income.

	Probabilistic Losses							
	<$30k		*$30k-50k*		*$50k-80k*		*>$80k*	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Intercept	-0.099	-0.104	0.001	-0.008	-0.095	-0.104	-0.091	-0.084
	[-0.291,0.084]	[-0.299,0.083]	[-0.223,0.228]	[-0.243,0.226]	[-0.293,0.100]	[-0.302,0.088]	[-0.311,0.139]	[-0.321,0.142]
Age	0.121	0.074	0.366	0.447	-0.331	-0.272	0.049	-0.145
	[-0.259,0.497]	[-0.330,0.484]	[-0.087,0.833]	[-0.062,0.965]	[-0.732,0.043]	[-0.718,0.166]	[-0.389,0.504]	[-0.635,0.330]
Anxiety		0.021		0.020		0.111		0.050
		[-0.533,0.583]		[-0.680,0.772]		[-0.536,0.756]		[-0.631,0.720]
Depression		-0.209		0.004		0.082		0.039
		[-0.776,0.354]		[-0.719,0.718]		[-0.581,0.741]		[-0.612,0.677]
Education		-0.105		-0.464		-0.011		-0.386
		[-0.486,0.285]		[-0.929,0.027]		[-0.412,0.399]		[-0.879,0.086]
Gender		0.080		-0.019		0.503		0.359
		[-0.303,0.462]		[-0.506,0.461]		[0.103,0.915]		[-0.124,0.855]
Health		-0.012		-0.253		0.131		0.173
		[-0.452,0.399]		[-0.767,0.280]		[-0.330,0.585]		[-0.355,0.685]
Amount		-0.130		-0.009		0.029		-0.076
		[-0.284,0.023]		[-0.168,0.156]		[-0.131,0.194]		[-0.267,0.118]
N	132	127	110	107	118	114	97	93
Information Criteria								
WAIC	-303.454	-272.932	-312.426	-303.053	-256.953	-239.970	-180.042	-176.463
LOO	-289.065	-258.561	-297.873	-289.298	-243.736	-226.447	-172.573	-167.799

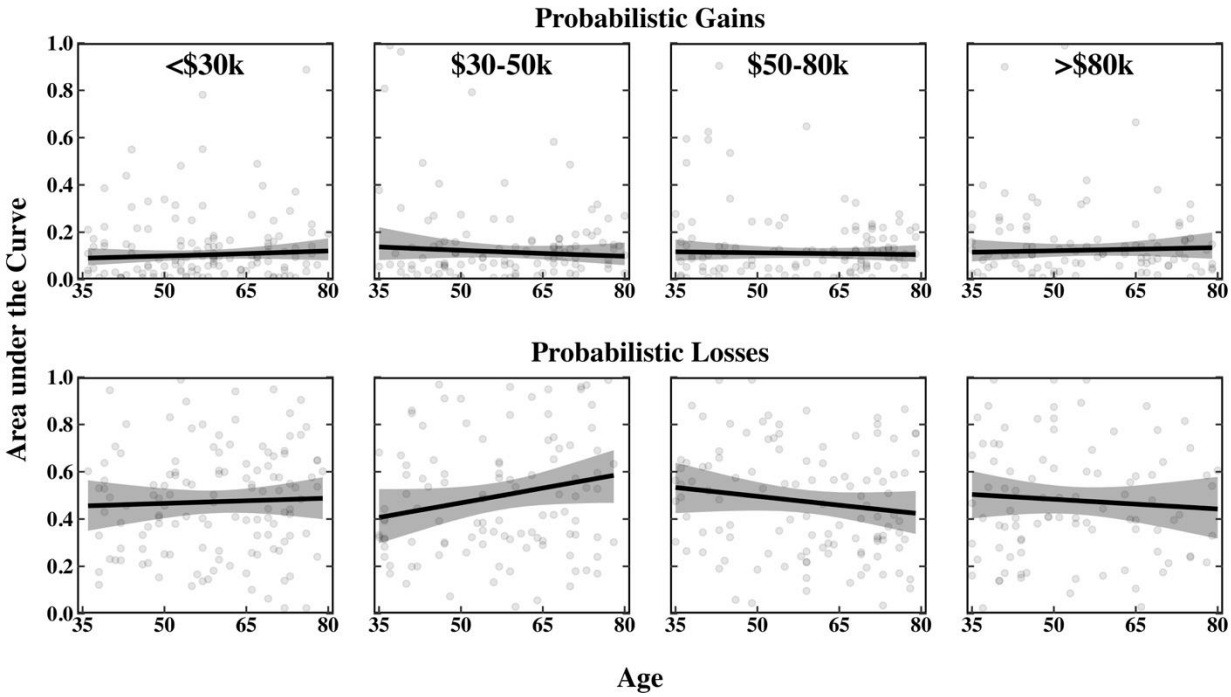

Figure 3.7 Estimated area under the curve as a function of age with anxiety, depression, gender, education, health, and amount statistically controlled at each income level in the experiments of discounting of probabilistic gains (top panels) and probabilistic loss (bottom panels). The black line represents the estimated mean of the area under the curve across ages, with shading depicting the 95% credible interval of that mean. The gray dots represent the mean of the Area under the Curve from each participant.

Two sets of nonlinear multilevel models were conducted to examine the effect of age on the parameters of the hyperboloid discounting function for each of the two types of probabilistic outcome. For the first set of nonlinear multilevel model, a significant effect of age was observed for the parameter *b* for probabilistic rewards such that estimated *b* increased as a function of age, while a significant effect of age was observed for the parameter *s* for probabilistic losses such that estimated *s* decreased as a function of age (see Table 3.8). Analysis for the second set of

nonlinear multilevel model, where other variables were statistically controlled, revealed a significant effect of age on both parameters in the discounting of both types of probabilistic outcome. More specifically, estimated *b* increased while estimated *s* decreased as a function of age for both probabilistic gains and probabilistic losses. Figure 3.8 depicts the effect of age on the estimated hyperboloid discounting function obtained from the nonlinear multilevel model with other variables statistically controlled in both types of probability discounting tasks.

Table 3.8 Model estimates obtained from Bayesian nonlinear analyses that examined the effects of age and other variables on the parameters of the hyperboloid discounting function in the discounting of probabilistic outcomes.

	Probabilistic Gains		Probabilistic Losses	
	Model 1	Model 2	Model 1	Model 2
b:Intercept	3.728	3.619	3.214	3.145
	[3.502,3.965]	[3.373,3.849]	[2.885,3.549]	[2.807,3.475]
b:Age	0.654	0.853	0.516	1.092
	[0.225,1.093]	[0.384,1.339]	[-0.145,1.123]	[0.397,1.760]
b:Anxiety		-0.036		1.158
		[-0.675,0.586]		[0.219,2.088]
b:Depression		0.621		0.684
		[-0.014,1.244]		[-0.241,1.596]
b:Gender		0.635		0.305
		[0.181,1.078]		[-0.351,0.966]
b:Health		0.175		1.285
		[-0.354,0.676]		[0.571,1.995]
b:Amount		-0.633		-0.732
		[-0.784,-0.475]		[-0.958,-0.504]
s:Intercept	-0.721	-0.629	-1.725	-1.685
	[-0.798,-0.641]	[-0.710,-0.546]	[-1.820,-1.625]	[-1.785,-1.591]
s:Age	-0.083	-0.294	-0.234	-0.384
	[-0.230,0.066]	[-0.459,-0.132]	[-0.428,-0.043]	[-0.595,-0.180]
s:Anxiety		-0.357		-0.294
		[-0.569,-0.136]		[-0.576,-0.011]
s:Depression		-0.018		-0.137
		[-0.239,0.194]		[-0.408,0.151]

s:Gender		-0.093		-0.206
		[-0.250,0.057]		[-0.407,-0.013]
s:Health		-0.205		-0.256
		[-0.376,-0.028]		[-0.463,-0.035]
s:Amount		0.753		0.242
		[0.688,0.821]		[0.166,0.317]
N	592	586	598	583
Information Criteria				
WAIC	-5087.294	-6574.635	-2233.450	-2248.316
LOO	-5042.828	-6499.747	-2212.576	-2226.468

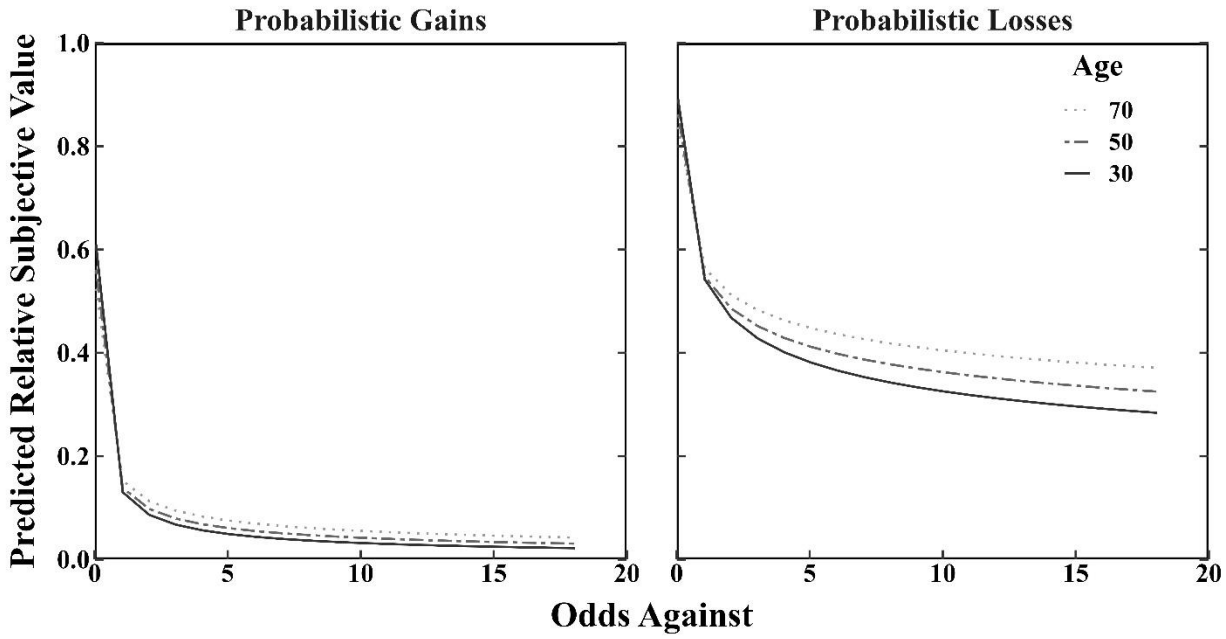

Figure 3.8 Estimated relative subjective value of the probabilistic reward (left) and probabilistic payment (right) as a function of the odds against based on the hyperboloid discounting model with anxiety, depression, gender, health, and amount statistically controlled. The lines represent the estimated mean of relative subjective value for each age across odds against.

Chapter 4: Discussion

The present study examined age-related differences in intertemporal and risky choice using the discounting framework. Individuals across the adult lifespan made intertemporal and risky decisions in fundamentally similar ways: both young and older adults discounted delayed/probabilistic gains and losses systematically as a function of delay/odds-against, and the hyperboloid function provided a good model of intertemporal and risky decision-making. In addition, while there was no magnitude effect in the discounting of delayed losses or the discounting of probabilistic losses, amount reliably affected the degree of discounting delayed and probabilistic gains, albeit in opposite ways: Whereas the degree of discounting delayed gains decreased with amount, the degree of discounting probabilistic gains increased with amount. This pattern of findings is consistent with prior research (e.g., for review, see Green et al., 2014). Notably, age-related differences in discounting were observed in the discounting of delayed and probabilistic gains and losses: Older adults chose larger, delayed rewards and smaller, sooner payments more often than younger adults, while there was no age-related difference in the discounting of either type of probabilistic outcome.

4.1. Delay Discounting Across the Adult Lifespan

The present study showed that for the discounting of delayed rewards, the effect of age depended on income. More specifically, older adults with lower incomes were more likely to choose the larger, later rewards than younger adults with lower incomes, consistent with the results of Wan et al. (*under review*), who also observed age differences in those with lower incomes (<$50K) but not those with higher incomes (>$80K). These findings support the buffering hypothesis that posits that emotional stability, which increases with age (Wan et al., *under review*) buffers older adults against distress that is associated with lower income. These results also are consistent

with Seaman et al. (2022), who reported shallower discounting by older adults, although the effect size was not sizable (*probability of direction* = .91). The present results explicate the small effect size reported in their meta-analysis: After all, if an effect occurs in only a portion of the population, then the effect as measured in the whole population will be smaller than that observed in the affected portion. Therefore, future research should consider age, income, and other demographic variables when evaluating the discounting of delayed rewards.

Unlike Wan et al. (under review) which only compared two annual household income groups (i.e., <$50K, >$80K), the present study included four income groups and localized age differences in discounting in those with lower incomes (<$30K). Choices involving delayed rewards have significant consequences for older adults who often have fixed incomes and/or age-related health problems, and those with lower incomes may have little room for error in their decision-making. Fortunately, the results of the present study provide evidence that when the choice is between a smaller, sooner reward and a larger, later reward, older adults with lower incomes are more likely to wait for the larger reward than younger adults and are on a par in their decision-making with those who have higher incomes.

With respect to the discounting of delayed losses, the effect of age across income groups showed the opposite pattern from that of the discounting of delayed rewards. An age effect was not observed in the participants with lower incomes (<$30K) but were observed in the participants with higher incomes: Older adults with higher incomes were more likely to choose the smaller, sooner payment than younger adults with higher incomes. The difference in the pattern of the effect of age across income groups between the discounting of delayed gains and delayed losses suggests they may rely on different underlying processes (Green & Myerson, 2013). The difference may also be, in part, because feelings of scarcity was not captured by asking for

annual household income. Older adults with higher incomes are more likely to have more savings and financial accumulations than younger adults with similar incomes or older adults with lower incomes. Two of the three amounts used in the present study (i.e., $2,500 and $30,000) were likely to be around, and above, the monthly household income for the lower-income participants, so making the choices of a smaller, sooner payment is difficult or even impractical for individuals with low incomes. This would explain the moderation effect of amount with age in the discounting of delayed losses because older adults likely have enough savings to cover the relatively large immediate losses compared to younger participants in the larger amount conditions. Nevertheless, the present results concentrate the issues in individuals with lower incomes and suggest possible differences in intertemporal decision-making between individuals with lower incomes and others. Indeed, Shah et al. (2012) showed that scarcity causes people to neglect future consequences of their decisions, which may at least partly account for the observed income differences in the discounting of both delayed gains and delayed losses. Future studies are needed to better understand the intertemporal decision-making in those with lower incomes.

The present study observed a moderation effect of amount in the discounting of delayed outcomes: In the discounting of delayed rewards, while younger adults discounting more steeply than older adults in the smaller amounts, younger adults' discounting was comparable to that of older adults at larger amounts. However, in the discounting of delayed losses, younger adults discounted at a similar rate as older adults at smaller amounts, but younger adults discounted more steeply than older adults at larger amounts. These findings suggest that previous studies reporting no age-related differences in the discounting of delayed losses need to be interpreted with cautious, given that relatively small amounts were involved in most of those studies, with

the largest amount being $84 (Halfmann et al., 2013; Löckenhoff et al., 2011; Sparrow et al., 2019; Sparrow & Spaniol, 2018), aside from Löckenhoff and Samanez-Larkin (2020). Although Löckenhoff & Samanez-Larkin included a $1,500 amount and found no moderation effect of amount, it is to be noted that they combined the results from the discounting of gains and losses in their analyses when examining a moderation effect of amount. If the moderation effects were in the opposite direction for the discounting of gains and losses, then there would be no interaction effect between age and amount.

In addition, because annual household income moderates the effect of age on the discounting of delayed losses, as the current study suggests, age-related differences may have been concealed by the main and moderation effects of income in previous studies. Another reason why age effects might not have been apparent in previous studies is their use of relatively small sample sizes. Only one of the five studies recruited more than 200 participants (N = 287; Löckenhoff & Samanez-Larkin, 2020), while none of the others recruited more than 100 participants (Halfmann et al., 2013; Löckenhoff et al., 2011; Sparrow et al., 2019; Sparrow & Spaniol, 2018).

There was no evidence in the present study that older adults discounted delayed outcomes more steeply (i.e., were more likely to choose smaller, sooner rewards and larger, later payments) than younger adults. This finding is consistent with the results of a study that found little support for increased discounting with age (e.g., emotional selectivity theory, Carstensen, 2006) and posited that this was because the improvement of affective forecasting skills in older adults lead them to imagine future events more vividly and thus discount less steeply than younger adults (Löckenhoff, 2011). It should be noted, however, that the present study did not find a difference in the magnitude of the age effect between the discounting of delayed gains and delayed losses, raising questions about the generality of the positivity effect, which postulates that older adults

tend to prioritize positive over negative material (Carstensen & Mikels, 2005) and of the finding that older adults are less sensitive to loss- than gain-cues (Löckenhoff et al., 2011; Samanez-Larkin et al., 2007).

4.2. Probability Discounting Across the Adult Lifespan

In contrast to the discounting of delayed outcomes, there was no sizable effect of age on the discounting of probabilistic gains and losses. The present findings with respect to age-related differences are consistent with those of Mata et al. (2011) who also reported no sizable age-related difference in risky decision-making. Such findings call into question the generality of the theory of age-related decline in cognitive resources. The theory posits that because older adults have fewer cognitive resources (Salthouse, 2010), they are more likely to choose the certain option because of its less complexity (Pachur et al., 2017; Zilker et al., 2020). The lack of an age-related difference in probability discounting also raises questions about the generality of theories of age-related motivational and affective changes, which suggest that aging is associated with increased focus on emotional regulation in which older adults are thus either more likely to prevent losses (Ebner et al., 2006) or less responsive to losses than younger adults (Löckenhoff, 2011).

Nevertheless, despite the lack of an age-related difference in risky choice, it remains to be determined whether there is an age-related difference in the discounting of probabilistic outcomes other than monetary rewards and payments. Decisions about mask wearing, social distancing, and vaccination, for example, all involve evaluating future outcomes that are inherently probabilistic, and age-related differences may be observed in the risky decision making of social and health-related outcomes. For example, older adults are more likely to engage in CDC-recommended mitigation behaviors (Masters et al., 2020; Myerson et al., 2022).

In addition, although simple discounting tasks like those used in the present study measure fundamental processes, everyday choices are often more complex and involve outcomes that are both gains and losses (e.g., financial investment decisions). Thus, age-related differences may thus become apparent when decisions become more complicated.

Dohmen et al. (2005) combined the evaluation of a gain with the evaluation of a loss, and with the outcome substantially delayed (i.e., 2 years after the decision), and did find age-related differences in risky choice. Likewise, it has been reported that older adults rely on simpler decision strategies that require less search and integration of information (Mata et al., 2010; Mata & Nunes, 2010), which then led to poorer-quality decision-making in older adults. Choices that require integrating the results of evaluations along multiple dimensions make these decisions more cognitively demanding. Unfortunately, information as to the role of discounting in complicated, everyday decisions is lacking because research has focused mostly on discounting as measured by simple choices of monetary rewards. Future studies need to move beyond simple choices like those of solely monetary gains or losses and investigate choice with qualitatively different outcomes resulting from different kinds of decisions varying widely in terms of difficulty (e.g., Estle et al., 2023; Vanderveldt et al., 2015).

The present study systematically evaluated the discounting of probabilistic gains and losses by individuals from different income brackets. We found that income neither affected probability discounting nor moderated with age, consistent with the findings of Jarmolowicz et al. (2012), which reported no correlation between probability discounting and income, and with those of Von Gaudecker et al. (2011), which found no income and wealth effect on risky choices. Taken together, the results from these studies suggest that income does not have any discernable effect on the degree of probability discounting. As mentioned above, there may be age-related

differences, however, when the risky choices involve multiple dimensions such as combinations of gains and losses. For example, in Dohmen et al. (2005), the evaluation of a gain was combined with the evaluation a loss, and with the outcome substantially delayed, and risky choice was found to decrease systematically with age and income, and females made fewer risky choices than males.

4.3. Aging, Discounting, and Psychological Distress

The COVID-19 pandemic has put the spotlight on the decisions people are asked to make and on the roles that age, psychological states, and individual differences in intertemporal and risky decision-making play in these decisions. The present study tried to disentangle these relations and focused on the roles of age and psychological distress in intertemporal and risky decision-making in simple choice situations. In the present study, unpacking the effects of psychological distress on discounting of delayed outcomes revealed that, whereas anxiety and depression did not significantly affect discounting of delayed rewards, anxiety and depression affected the discounting of delayed losses. More specifically, adults with higher anxiety chose the later, larger payment more often than adults with lower anxiety, and participants with higher depression chose the smaller, sooner payment more often than participants with lower depression.

Choices in situations involving options with delayed losses have significant consequences for older adults who have age-related health problems and may not earn back the money spent or lost, and it perhaps is more consequential for those with lower incomes who do not have sufficient income and savings to protect them from financial and medical emergencies. Indeed, the present study found that in the discounting of delayed losses, there was a significant effect of anxiety for the lower income group (i.e., <$30K) but not for the other income groups. Moreover,

unlike the discounting of delayed rewards where older adults with lower incomes did not differ in discounting from those with higher incomes, the older adults with lower incomes discounted delayed losses at a similar rate as the younger adults with lower income. Psychological distress, therefore, may lead to sub-optimal intertemporal decision-making of losses in adults with lower incomes and even older adults with lower incomes whose buffer of emotional stability may be overshadowed by the detrimental effect of psychological distress.

With respect to the discounting of probabilistic outcomes, the present study found a significant effect of anxiety in the discounting of gains but not losses. More specifically, adults with higher anxiety chose the larger, probabilistic reward more often than adults with lower anxiety. The findings of the anxiety effect on the discounting of probabilistic rewards are consistent with those of Maner et al. (2007) who, using the balloon analog risk task, found that patients with anxiety disorder were more risk-averse than control participants. However, although the balloon analog risk task may be analogous to choices involved in the discounting of probabilistic rewards, given the well-established fact that individuals weight potential losses more than potential gains (lose aversion; Kahneman & Tversky, 2013), it is difficult to differentiate an anxiety effect on risk aversion from that on loss aversion. The present study added to the literature that the effect of anxiety was observed only for risky choices involving gains but not those involving losses. The current findings are consistent with those of Charpentier et al. (N = 50; Charpentier et al., 2017), but using the discounting framework and with a much larger sample and greater statistical power. In addition, the lack of an effect of depression on the discounting of probabilistic outcomes is consistent with those of previous studies that found no relation between depression and risky decision-making (Charpentier et al., 2017; Maner et al., 2007; Mitte, 2007).

4.4. Discounting and Psychological Construct

The present findings have implications for understanding relations among intertemporal and risky decision-making of gains and losses. These four types of discounting were constructed to be analogous to one another to better reveal similarities and differences among these forms of choice behavior (Green & Myerson, 2004). It often is assumed that one process underlies all forms of discounting (Bickel & Marsch, 2001; Odum, 2011). Based on this assumption, research has mostly focused on the degree of discounting of delayed gains for studying impulsivity and/or lack of self-control, since the procedures and measures for the discounting of delayed gains have been well developed and widely used (e.g., Monetary Choice Questionnaire; Kirby et al., 1999). The literature on other types of discounting, such as the discounting of delayed losses, has been meager and sometimes even inconsistent (Harris, 2012).

However, if instant gratification and risk-taking were manifestations of a single impulsivity construct, a significant age-related difference in one discounting task should be observed in the other discounting tasks as well. Contrary to this prediction, however, the present study failed to reveal a consistent age-related difference across the four types of discounting: an age-related difference was observed in the discounting of the delayed outcomes but not the probabilistic outcomes. Moreover, within the discounting of delayed outcomes, there was an age effect in the lower income group but not in the higher income group in the discounting of delayed gains, whereas there was an age effect in the lower income group for the discounting of delayed losses. In addition, the hypothesis of a single impulsivity construct also predicts that amount will have the same effect on both delay and probability discounting, but smaller delayed rewards were discounted more steeply than larger delayed rewards, while smaller probabilistic rewards were discounted less steeply than larger probabilistic rewards, and magnitude effects were not

observed for the discounting of losses. The difference in the magnitude effect between discounting of gains and losses and the discounting of delayed and probabilistic gains is consistent with previous results (for review, see Green, Myerson, & Vanderveldt, 2014; Green & Myerson, 2010).

The present finding of significant age effects in the discounting of delayed outcomes but not in the discounting of probabilistic outcomes further strengthens the argument against a single impulsivity construct, suggesting instead that different traits underlie the different types of discounting (Green & Myerson, 2013). Therefore, although the discounting of delayed rewards is important, a much broader examination of discounting on multiple dimensions will be essential for a more complete understanding of age-related differences in decision-making.

Chapter 5: Conclusion

The main goal of the present study was to examine age-related differences in intertemporal and risky choices that involve gains and losses within the discounting framework. There has been substantial theoretical and empirical heterogeneity in the age-related literature on intertemporal and risky decision-making. Although two meta-analyses (Mata et al., 2011; Seaman et al., 2022) revealed little sizable age-related differences in intertemporal and risky decision-making, the results from a number of studies suggest that the heterogeneity reported is, in part, due to the demographics of the groups that were studied. The lack of attention to demographic variables is unfortunate because many problematic behaviors that covary with degree of discounting may be related to age-related cognitive and affective changes.

In addition, the present study reported critical differences in intertemporal choices involving gains and losses between lower and higher income participants. Older adults with lower incomes are of special interest because they may not be able to earn back the money lost to cover their financial and medical needs. In the present study, although older adults with lower incomes discounted delayed rewards less steeply than younger adults with lower incomes, no age-related difference in the discounting of delayed losses was observed between older and younger adults with lower incomes. More research on age-related differences in the discounting of delayed outcomes, especially for individuals with low annual household incomes and financial assets, is badly needed to better understand the causes behind age-related and socioeconomic differences in discounting.

Finally, much of the research on discounting assumes that various kinds of discounting are well-represented by the simple situation involving the discounting of delayed gains and reflects a single impulsivity trait, the present results show that such an assumption in untenable. The

findings of differences due to age, income, and amount on the four types of discounting, suggest that different impulsivity constructs underline different types of discounting. There remains a large gap between current knowledge concerning the processes underlying discounting and the roles of individual differences in those processes. More research is needed to fully understand the role of discounting in more complicated situations than those studied here. It remains to be seen how age-related and socioeconomic differences are involved in more complicated, and everyday-type decision-making tasks such as those involving outcomes that are both delayed and probabilistic. The results from such studies will have both theoretical and applied implications for the development of effective and efficient financial and health-related public policies can be applied to adults of all ages.

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