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Factors affecting temporal discounting in older adults

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I. Introduction

People often make decisions in which they face a trade-off between smaller rewards that are immediate and larger rewards that are delayed. These "intertemporal choices" can be minor (e.g., deciding whether to have a drink tonight or to feel sharp in the morning), or extremely consequential (e.g., deciding when to start collecting Social Security benefits). In general, people prefer to receive rewards sooner rather than later. This tendency is called temporal discounting, since people "discount" the value of future rewards. Although most individuals show temporal discounting, the extent to which they do varies widely from person to person. These individual differences in temporal discounting rate have been associated with real-world behaviors, with people who discount to a greater degree being more likely to smoke (Bickel, Yi, Kowal, & Gatchalian, 2008; Yi & Landes, 2012), overeat (Jarmolowicz et al., 2014; Schiff et al., 2015), gamble (Reynolds, 2006), borrow excessively on credit cards (Meier & Sprenger, 2010) and text while driving (Hayashi, Russo, & Wirth, 2015). Therefore, it is important to understand the cognitive and neural mechanisms that underlie these individual differences.

Understanding individual differences in temporal discounting as people age is especially important. The global population is aging rapidly, increasing the relative number of older decision makers (United Nations, 2007). Middle-aged and older adults make many important economic decisions, including choices about savings and investments. They also make many health decisions, which often involve trade-offs between smaller/sooner and larger/later rewards. Moreover, engaging in healthy behaviors becomes increasingly important for preventing disease as people age, and a lower discount rate is associated with healthy behaviors, such as exercise, in older adults (Tate, 2015). Finally, difficulties with financial decision making can be an early sign of dementia (Barnes et al., 2014).

Despite the importance of knowing how temporal discounting might change with aging, the existing literature on temporal discounting in older adults is mixed. Some studies have shown decreased temporal discounting (Eppinger, Nystrom, & Cohen, 2012), others show increased temporal discounting (Read & Read, 2004), and yet others show no differences between older and younger adults (Chao, Szrek, Pereira, & Pauly, 2009; Green, Myerson, & Ostaszewski, 1999). This inconsistency may stem from variability in age-related decline of cognitive functions that contribute to decision making (Huffman, Maurer, & Mitchell, 2017; James, Boyle, Yu, Han, & Bennett, 2015a). Two such cognitive functions that may be important for individual differences in temporal discounting are *executive function* and *declarative memory*. Both executive function and declarative memory decline as people age (Buckner, 2004; Park et al., 1996) at rates that vary across individuals (Rubin et al., 1998). Here, we examine this variability in cognitive abilities in a well-characterized cohort of older adults at the Penn Memory Center to study the relationship between differences in temporal discounting and differences in both executive function and declarative memory.

Executive functions are used to control behavior in order to achieve goals. For example, the ability to keep a rule in mind and implement it, the ability to flexibly change your behavior when necessary, and the ability to remember information for a very short period of time are all considered executive functions. It has been proposed that executive function is important for making future-oriented intertemporal choices because it enables one to inhibit impulsive responses to choose immediate rewards. For example, you might feel tempted to have a cigarette or a dessert now, but executive function might help you keep your long-term goal (better health, smaller waistline) in mind so that you do not give in to the temptation. There is some evidence linking the neural system of executive function (which is localized to the brain's frontal lobe) to lower temporal discounting. In functional neuroimaging studies, frontal regions tend to be more active when people choose future rewards over immediate ones (McClure, Laibson, Loewenstein, & Cohen, 2004). In the current study, we related performance on two well-established measures of executive function—the Trail Making Test and lexical fluency—with a measure of temporal discounting. These measures will be explained in more detail in Section II (*Data and methodology*).

Declarative memory, on the other hand, refers to long-term memory, both for facts (e.g., knowing what a pension is) and for specific events from one's life (e.g., remembering the moment when you learned what a pension was). It may seem less intuitive that declarative memory would be involved in intertemporal choices, but neuroscience research has shown that imagining the future relies on the same neural circuitry as recalling the past. Being able to imagine the future vividly can aid the decision-maker in choosing future rewards. For instance, imagining that you will be traveling a lot as a retiree will make you more likely to save money for retirement instead of spending it now. There is some evidence that the declarative memory system is involved in intertemporal choices, mostly from studies trying to manipulate these choices: imagining positive future events and retrieving positive autobiographical memories decreases temporal discounting in young adults (Benoit, Gilbert, & Burgess, 2011; Lempert, Speer, Delgado, & Phelps, 2017; Palombo, Keane, & Verfaellie, 2015; Peters & Büchel, 2010; Sasse, Peters, Büchel, & Brassen, 2015). Here, we related performance on two measures of declarative memory – episodic memory retrieval and semantic fluency – to temporal discounting. These measures will also be described in Section II.

Despite the large literature suggesting that both declarative memory and executive function play a role in intertemporal choice, few studies have examined which of these cognitive processes underlies *individual differences* in temporal discounting. This is a challenging problem to study in young adults because young adults perform very well on both executive function and declarative memory tasks, and performance on the two tasks is usually correlated within an individual. Therefore, we used a well-characterized, diverse older adult sample in which decline in these two systems is variable. We tested two alternative hypotheses: 1) that better declarative memory would be associated with reduced

discounting, or 2) that better executive function would be associated with reduced discounting.

In addition to measuring temporal discounting, we also assessed risk preferences with a risky choice task. There are two reasons for this. First, a person's risk tolerance tells us about the subjective utility that they place on different monetary amounts. Therefore, taking risk tolerance into account gives us a more accurate estimate of utility, which then makes estimates of temporal discounting rate more accurate. Second, we wanted to see if any association between cognitive measures and temporal discounting was specific to intertemporal choices. After all, better cognitive abilities have been associated with both lower temporal discounting and more risk-neutrality. People who are more educated (Donkers et al., 1999) and have higher fluid intelligence (Burks, Carpenter, Goette, & Rustichini, 2009), are more likely to gamble when gambles have a higher expected value (e.g., they will choose $30 with a 50% chance over $14, because the former has the higher expected value of $15). In other words, they are closer to risk-neutral and thus more risk-seeking than average. In this study, we additionally examined the relationship between risk preferences and both executive function and declarative memory.

II. Data and methodology

Participants. One hundred older adults completed the UDS neuropsychological testing battery, as well as an intertemporal choice task and a risky choice task. See **Table 1** for sample characteristics. All subjects are part of the Clinical Core cohort of the University of Pennsylvania Alzheimer's Disease Core Center (ADCC). All participants completed the National Alzheimer Coordinating Center (NACC) Uniform Data Set (UDS) neuropsychological test battery (https://www.alz.washington.edu/WEB/data_descript.html) within one year of completing the decision tasks (range: 0 – 315 days; M = 87.76 days; SD = 70.62 days). To ensure sufficient variability in our cognitive measures, we included individuals with Mild Cognitive Impairment (MCI) in our sample. MCI is a syndromic label often conceptualized as an intermediate stage between normal cognitive aging and mild dementia. While ~50% of MCI patients likely have underlying Alzheimer's disease pathology, the category is heterogeneous and not indicative of a specific pathological process. Diagnoses were based on a consensus conference attended by Alzheimer's Disease clinical experts. In all analyses, we controlled for the effects of age, gender and years of education. This study was approved by the Institutional Review Board of the University of Pennsylvania.

Table 1. Characteristics of participants (N = 100)

Characteristic	Mean, SD, Range (or %)
Age	72.01 (6.82, 58-93)
Sex	58% Female, 42% Male
Race	62% White, 36% Black, 2% Multi-racial
Years of education	15.96 (2.82, 9-20)
Diagnosis	74% Cognitively normal; 26% MCI
Cognitive measures: Raw scores	**Mean, SD, Range**
Word List Memory Delayed Recall	7.5 (2.61, 0-10)
Craft Story Delayed Recall	13.63 (5.90, 0-23)
Benson Complex Figure Delayed Recall	9.93 (4.43, 0-16)
Semantic fluency (Animals)	20.89 (6.03, 9-41)
Semantic fluency (Vegetables)	13.88 (4.71, 0-30)
Lexical fluency (F-words)	15.08 (4.66, 2-26)
Lexical fluency (L-words)	13.78 (4.15, 5-25)
Trail Making Test (Part B minus Part A) RT	46.61 (25.48, 10-153)*

MCI = mild cognitive impairment; RT = reaction time. *N = 4 participants excluded for not completing Trail Making Test Part B in the allotted time (N = 1) or for having an RT on Trail Making Test Part B that was more than 3 SD > mean (N = 3; times of 280 s, 300 s, and 300 s).

Procedure. Participants completed computerized choice tasks measuring temporal discounting and risk tolerance. Subjects were given extensive instructions as well as practice trials to confirm that they understood the tasks fully. They were also instructed that one of their choices would be realized at the end. One choice from either the intertemporal choice or risky choice task was randomly selected to determine a bonus. Since participants did not know which choice would count, their best strategy was to treat each one as if it were the one that counts. The bonus was paid using a pre-paid debit card on the day the payment was due. All payments were made this way, so we introduced no differences in the transaction costs for different types of payments (risky choice task payment, intertemporal choice immediate payment or intertemporal choice delayed payment). For delayed payments, subjects received payment on their Clincard on the date corresponding to the delay for the chosen option. The procedure lasted about 15 minutes. The tasks were self-paced.

- **Risky choice task.** On each trial of this task (60 choices), participants chose between a small amount of money ($1-$68) available for sure, and a larger amount of money ($10-$100) available with a 50% chance. All risky options entailed a 50% chance of the larger amount and a 50% chance of $0. If a participant chose the risky option on the randomly selected trial, a coin was flipped to determine if they would receive payment or $0. We obtained two measures from this task. First, as our measure of risk neutrality (or expected-value maximizing), we calculated the proportion of choices in the risky choice task on which the participant either chose the gamble when the expected value (amount * probability) of the gamble was higher *or* chose the safe option when the expected value of the safe option was higher. Higher values here indicate that the person's choices are closer to risk-neutral (a completely risk-neutral chooser would maximize expected value on 100% of trials). We also fit a power-law model to the choices to estimate a risk tolerance

parameter for each person. Note that risk tolerance is correlated with risk neutrality (a risk-neutral chooser would select the gamble on ~68% of trials), but they can be differentiated by the subset of trials where the expected value of the safe option was higher; a risk-neutral chooser would pick the safe option in that case, but someone with a high risk tolerance would still favor the gamble.

- **Intertemporal choice task.** On each trial of this task (51 choices), participants chose between a small amount of money available immediately and a larger amount of money available at a specified delay. The delayed outcome was always one of three amounts ($25, $30, $35). Delays ranged from 1-180 days. We obtained discount rates by fitting a hyperbolic model to each individual's choices and estimating the rate of decline of the hyperbola for each person. The amounts of the rewards were first transformed to subjective utilities using the risk tolerance parameters obtained from the analysis of the risky choice data.

- **Executive function measures.** We used two well-established measures of executive function: the Trail Making Test and lexical fluency. The Trail Making Test is a widely used neuropsychological measure of frontal executive function (Davidson, Gao, Mason, Winocur, & Anderson, 2008; Stuss et al., 2001) involving attention, cognitive flexibility (Kortte, Horner, & Windham, 2002), and maintaining and implementing a rule. Lexical fluency probes the ability to generate words beginning with a certain letter (e.g., "F"). This task has been shown to depend on the frontal lobe (Mummery, Patterson, Hodges, & Wise, 1996; Tupak et al., 2012) since it involves keeping rules in mind (e.g., no proper nouns, no number words) and rapidly switching between categories of words.

  - *Trail Making Test ("Trails B-A"; Reitan, 1992).* This test is given in two parts, A and B. Part A involves drawing a line connecting consecutive numbers from 1 to 25 (the numbers are scattered randomly on a page). Part B involves drawing a similar line, connecting alternating numbers and letters in sequence (i.e., 1-A-2-B, etc.). The time to complete each "trail" is recorded. The difference between Part B time and Part A time is considered a measure of executive function, since performance on Part A accounts for any motor or processing speed differences between subjects. Because the distribution of time is skewed, scores were natural log-transformed before any analyses were conducted. "Trails B-A" refers to the (log-transformed) difference in reaction time between Part B and Part A.

  - *Lexical fluency (Benton & Hamsher, 1976).* Lexical fluency was measured by having the participant list as many words beginning with the letter "F" as they could in 60 seconds and as many "L" words as they could in 60 seconds. The total number of correct and unique "F" and "L" words were counted. Scores on the F-word and L-word tasks were transformed to z-scores and then averaged.

- **Declarative memory measures.** The neuropsychological battery of the Penn ADCC contains several tests that measure declarative memory ability. We constructed a composite score of three tasks that measured *episodic* memory (or memory for recent personal events). We also looked at semantic fluency, which taps into semantic memory (or memory for facts about the world).

  - *Word List Memory test (Morris et al., 1989).* Participants were presented with a list of 10 words that were read to them at a constant rate of 1 word every 2 seconds. The word list was presented 3 consecutive times, in randomized order. After every presentation, participants were asked to recall the words. After a short delay of approximately 5 minutes, the participant was asked to recall as many of the ten words as they could. We included this Delayed Recall score as a measure of memory performance.

- *Craft Story Delayed Recall (Monsell et al., 2016).* The Craft Story 21 is a paragraph story recall test, or a test of logical memory (Wechsler, 1987). The examiner read a story aloud once, then asked the participant to repeat the details of the story in the same words read by the examiner or in their own words. After approximately 15 minutes (mean = 14.52 min; SD = 2.3), the participant was asked to recall the story again. Points for verbatim and paraphrase recall were summed individually. For this study, only the delayed paraphrase recall score (range: 1 to 25) was analyzed.
- *Benson Complex Figure recall (Possin, Laluz, Alcantar, Miller, & Kramer, 2011).* In this assessment of visuospatial memory, participants are first asked to copy a complex figure (a simplified version of the Rey-Osterrieth complex figure) and then to draw it from memory approximately 10-15 minutes later. Their recall score is based on the number of correct elements present in the figure drawing. We used their recall score as our third measure of episodic memory. Episodic memory scores on the delayed recall trial of these three measures were transformed to z-scores and then averaged, resulting in a composite memory score. Z-scores were calculated with respect to the mean and standard deviation of the cognitively normal subgroup.
- *Semantic fluency (Morris et al., 1989).* Semantic fluency was measured by having participants name as many animals as they could in 60 seconds and as many vegetables as they could in 60 seconds. The total number of correct and unique animal and vegetable words were tallied. Scores on animal and vegetable tasks were transformed to z-scores and then averaged.

III. Key results

- **Declarative memory, but not executive function, is associated with temporal discounting in older adults.** A composite episodic memory score (combining three neuropsychological measures; see Section II. *Data and methodology)* was significantly correlated with discount rate. Specifically, individuals who were better able to retrieve memories after a short delay were more patient in their decision making (Fig. 1A). Semantic fluency performance was also correlated with discount rate (Fig. 1B). People who were able to list more examples of animals and vegetables in this task were also more likely to select larger, later rewards over smaller, sooner rewards. In contrast, performance on our two measures of executive function—Trails B-A (i.e., the difference in completion time between Trail Making Test B and Trail Making Test A; see Section II. *Data and methodology)* and lexical fluency—were not correlated with temporal discounting (Fig. 1C, D).

Figure 1.

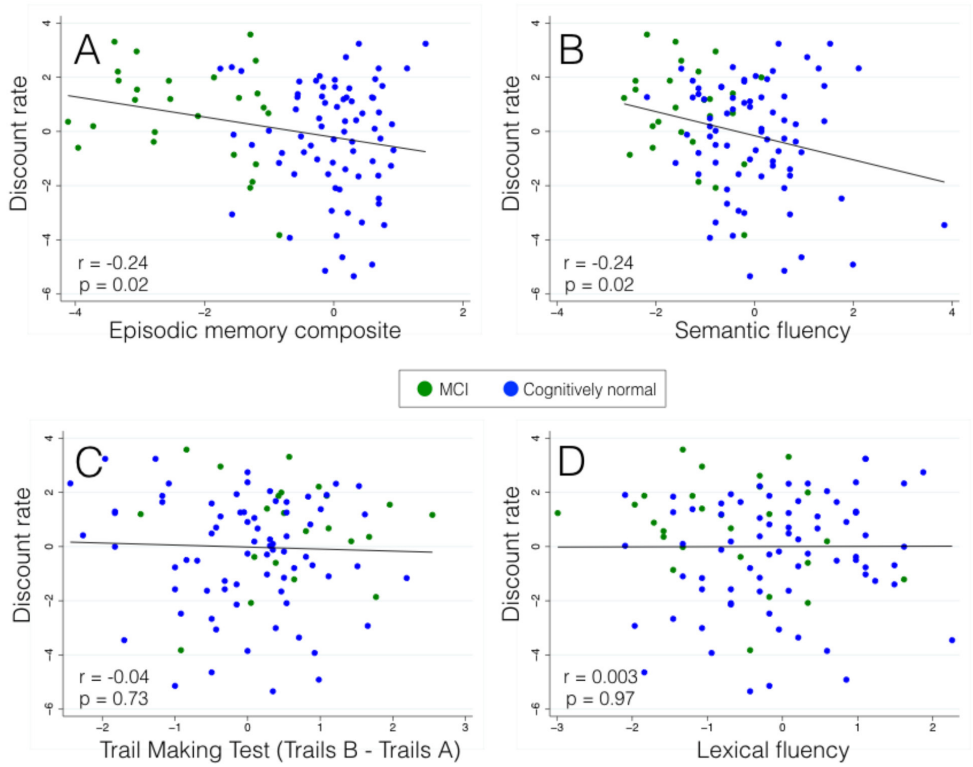

Fig. 1. Measures of declarative memory, episodic memory retrieval (A) and semantic fluency (B), are significantly correlated with temporal discounting rate, but performance on executive function measures, Trails B-A (C) and lexical fluency (D), is not. Residual plots (after adjusting for age, gender, and years of education) are shown. MCI = Mild Cognitive Impairment.

- **Executive function, but not declarative memory, is associated with risk neutrality in older adults.** There was no relationship between measures of declarative memory and risk tolerance, or between declarative memory and the proportion of trials on which the person selected the option with higher expected value (Fig. 2A, B). Thus, the association between declarative memory measures and temporal discounting is specific to temporal discounting and does not extend to decisions in the face of risk. Trails B-A, however, was significantly correlated with the proportion of choices in which the decision maker chose the higher expected-value option (Fig. 2C, D). In other words, individuals who were faster to complete Trails B (relative to Trails A) were closer to risk-neutral. A similar relationship was found for lexical fluency at a trend level. These two executive function measures were not correlated with risk tolerance in general, however. Therefore, people with better executive function are not estimated to take more risks overall, but they are more likely to calculate expected value when making risky decisions and choose in order to maximize it.

Figure 2.

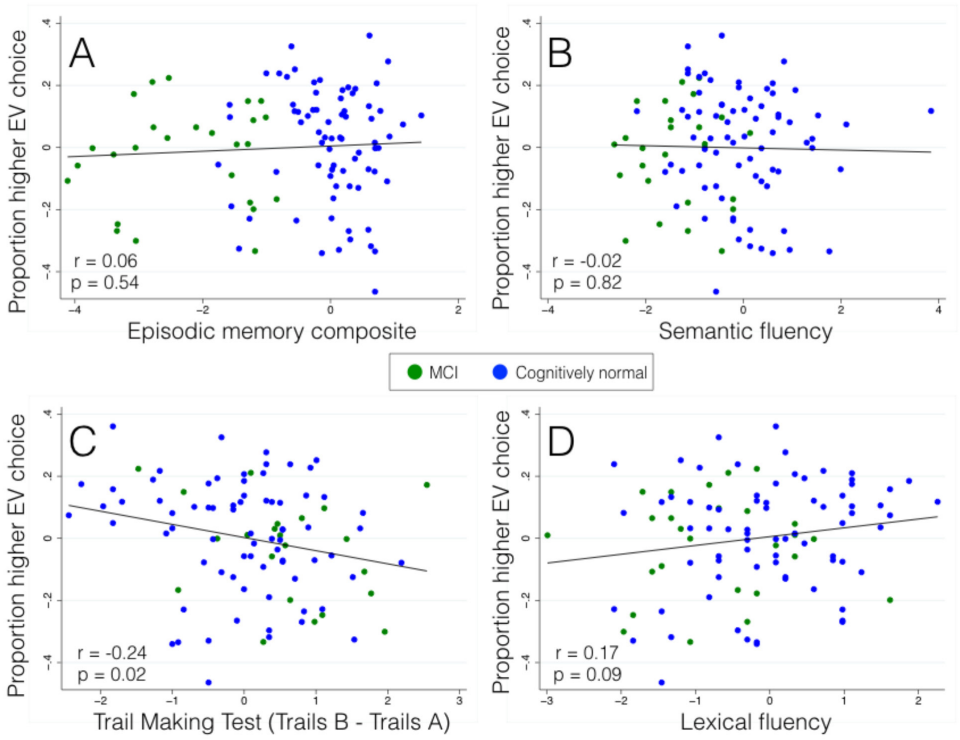

Fig. 2. Measures of declarative memory, episodic memory retrieval (A) and semantic fluency (B), are not significantly correlated with risk neutrality (i.e., the proportion of choices on which the higher expected value option was chosen in the risky choice task). Performance on executive function measures, Trails B-A (C) and lexical fluency (D), was related to risk neutrality. Residual plots (after adjusting for age, gender, and years of education) are shown. EV = expected value; MCI = Mild Cognitive Impairment.

- **Individuals with mild cognitive impairment showed increased temporal discounting.** Perhaps not surprisingly given the relationship between declarative memory ability and temporal discounting, there was a significant effect of diagnosis (mild cognitive impairment vs. cognitively normal) on discount rate, with MCI participants displaying increased temporal discounting overall. The diagnosis had no influence on risk tolerance or on the proportion of choices where the higher expected-value option was chosen in the risky choice task. Although we specifically recruited MCI patients with memory impairment, MCI participants were impaired on both declarative memory measures and executive function measures compared to cognitively normal older adults. This suggests that our results are not purely due to people with MCI having lower cognitive function and being worse at making decisions in general.

IV. Conclusion

In this study, we collected intertemporal choice and risky choice data from a diverse group of cognitively normal and MCI older adults who are part of a longitudinal cohort at the Penn Memory Center. We report three key findings: (1) better declarative memory, or the ability to remember facts and events, was associated with reduced temporal discounting, (2) executive function, or the ability to maintain goals and rules in mind, was associated with more risk neutrality, and (3) individuals

with MCI showed increased discounting rates (but no differences in measured risk attitudes) compared to cognitively normal individuals.

This paper sheds light on the inconsistent literature concerning temporal discounting and aging. We found no relationship between age and temporal discounting in this sample, and declarative memory ability and temporal discounting were associated even when controlling for age. Declarative memory is one of the first cognitive abilities to decline as individuals age (Buckner, 2004; Nyberg, 2016; Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012). Thus, it is possible that papers that found increased impulsivity with age may have not taken into account individual differences in memory abilities. Some previous research has shown that global cognition is related to temporal discounting in older adults (Boyle et al., 2012; Huffman et al., 2017) and that decline in global cognition leads to increased temporal discounting (James, Boyle, Yu, Han, & Bennett, 2015b). To our knowledge, however, this is the first report to find that the specific cognitive process underlying individual differences in temporal discounting is declarative memory, not executive function. We note, however, that even declarative memory is comprised of a few processes. Since both episodic (memory for events) and semantic (memory for facts) memory were associated with discount rate here, we cannot say which of these processes is more important for promoting patient decision making.

Performance on standard measures of executive function (Trails B-A and lexical fluency) was not associated with temporal discounting. This may be surprising to some, since executive function is often seen as synonymous with "self-control," and people think of intertemporal choices as taxing self-control. Of course, it is possible—even likely—that executive function is involved in some intertemporal choices, especially when the choice is a difficult one, but our findings suggest that declarative memory abilities underlie individual differences in temporal discounting more so than executive function abilities. This result is also consistent with the findings that taxing executive function does not lead to changes in temporal discounting (Olschewski, Rieskamp, & Scheibehenne, 2018), but encouraging people to imagine the future or recall the past decreases temporal discounting (Lempert et al., 2017; Peters & Büchel, 2010).

Executive function, however, was correlated with the tendency to take calculated risks in a risky choice task, consistent with previous research (Benjamin, Brown, & Shapiro, 2013; Boyle, Yu, Buchman, Laibson, & Bennett, 2011; Burks et al., 2009). People who performed better on Trails B-A and lexical fluency made choices that were closer to risk-neutral (and maximized expected value). We believe that individuals with better executive function are better at calculating expected value and using that information to make choices.

We see two important future directions for this work. First, our results suggest that temporal discounting may increase with aging to the extent that declarative memory declines. However, we cannot draw this conclusion from our cross-sectional investigation. Future research with a longitudinal design, perhaps with the same cohort used in the current study, will reveal whether declarative memory decline has a causal influence on intertemporal decision making. Another important future direction is to link neural measures of memory and executive function with time and risk preferences. Based on these results, and previous research with young adults (Owens et al., 2017; Pehlivanova et al., 2018), we would predict that structural integrity of the medial temporal lobe in older adults would be correlated with temporal discounting. We would also expect that frontal lobe structural integrity would be associated with risk neutrality.

In conclusion, the current study sheds light on the cognitive mechanisms underlying individual differences in temporal discounting, and it contributes to our understanding of decision making in aging. We hope that this knowledge will aid in the development of more targeted interventions to improve decision making, especially as cognition declines.

V. References

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