

Compensating Cognitive Capabilities, Economic Decisions, and Aging

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Abstract

Older adults have lower levels of fluid intelligence than younger adults, but decision-making studies show a mixed picture of performance over the lifespan: older adults often do worse but some studies find no difference or even better performance. We propose that age differences in decision performance result from the interplay between two sets of capabilities, one which finds worse performance for older adults (e.g., fluid intelligence and executive functions) and one on which older adults are better (e.g., crystallized intelligence). Specifically, we hypothesized that higher levels of crystallized intelligence help offset lower levels of fluid intelligence for older adults. The performance of older adults relative to younger adults depends on the relative importance of each capability for the decision task. We tested this *compensating capabilities* hypothesis in a broad sample of younger and older adults, collecting a battery of standard cognitive measures and measures of economically important decision-making “traits”—including temporal discounting, loss aversion, financial literacy, and debt literacy. We found that older participants performed as well as or better than younger participants on these four decision-making measures. Structural equation modeling revealed that fluid intelligence, crystallized intelligence, and inhibitory control were significant partial mediators of decision-making age differences. Specifically, we found that older participants’ greater crystallized intelligence offset their lower levels of fluid intelligence for financial and debt literacy as well as temporal discounting, but not for loss aversion. These results have important implications for public policy and for the design of effective decision environments for older adults.

Keywords: Cognitive Aging; Decision-making; Fluid Intelligence; Crystallized Intelligence; Inhibitory Control; Financial Literacy

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1. INTRODUCTION

Lay people simultaneously hold two conflicting views about aging: that age brings wisdom, and that age brings senility. The idea that “older is wiser” has some empirical support: older adults show better emotion regulation (Charles & Carstensen, 2010; Samanez-Larkin & Carstensen, 2011), better reasoning about interpersonal and intergroup conflicts (Artistico, Cervone, & Pezzuti, 2003; Grossmann et al., 2010; Thornton & Dumke, 2005), and, most relevant for the current research, higher levels of *crystallized intelligence*—i.e., experience and accumulated knowledge—into their 60s, after which it plateaus (Salthouse, 2004).

However, cognitive aging research has also shown that a wide range of cognitive capabilities, generally categorized as *fluid intelligence*, i.e., related to the ability to generate, transform and manipulate information, decline with age, including reasoning, processing speed, and working memory (Salthouse, 2004, 2010; Schaie, 1993). Fluid intelligence seems critical for decision-making, and average people in their 60s will have lost more than one standard deviation in fluid intelligence since their 20s. Given the decline of these capabilities with age, *do* people become wiser decision-makers as they age, or do they get worse? If older decision-makers are wiser, *how* do they make up for their lower levels of fluid intelligence?

Papers in this area have typically examined the impact of age on either cognitive capability *or* on decision-making. In this paper we examine the relationship among these measures, assessing younger and older adults on several important components of decision-making and directly relate observed differences in decision performance to differences in cognitive capabilities. We focus on several decision-making *traits*—for which we demonstrate stability and measurement reliability—known to affect the quality of a wide range of important real-world economic decisions.¹ Specifically, we examine the respective roles of older adults’

¹ We refer to these as “traits” because although they themselves are not real-world decisions, they form the basis for a wide range of real-world decisions.

lower levels of fluid intelligence and higher levels of crystallized intelligence, proposing that both fluid and crystallized intelligence can contribute to better decision performance on many tasks. The apparent age differences in decision performance result from the interplay between these cognitive capabilities. We posit that older adults' higher levels of crystallized intelligence may offset their lower levels of fluid cognitive capabilities for a wide variety of decisions in which both the processing of new information and past experience play a role. We call this interplay the *compensating capabilities* hypothesis.

We first review what is known about the relationship between age and cognitive capability, describing capabilities that increase and decrease with age. We then review the literature on individual differences in decision-making, focusing on those abilities most likely to directly impact the decisions of an aging population and discuss how these results might be integrated with age differences in cognitive capabilities. Our main focus is a large-scale, multi-wave study that assesses these cognitive capabilities and decision-making traits in both younger and older adults, thus showing the effects of the compensating capabilities of crystallized and fluid intelligence on decision performance.

2. COGNITIVE CAPABILITIES, AGE, AND DECISION-MAKING

2.1 Declining Capabilities: Fluid Intelligence and Inhibitory Control

Cognitive aging research has consistently found that fluid cognitive capabilities linearly decline with age starting from early adulthood, including processing speed and efficiency (Li et al., 2004; Lindenberger, Mayr, & Kliegl, 1993; Salthouse, 1991, 1994, 1996), working memory (McArdle, Ferrer-Caja, Hamagami, & Woodcock, 2002; Salthouse, 1992), explicit learning (Salthouse, 2006), and attention and problem solving (Craik & Salthouse, 2000). These declines especially impact complex or novel tasks that require more active processing (Zacks, Hasher, & Li, 2000).

Another important ability that declines with age is inhibitory control, or the ability to

inhibit prepotent responses. One of the three core executive functions—along with shifting and updating—inhibitory control is important when making a good decision requires overcoming a default, habitual, or salient first response (Friedman et al., 2006; Salthouse, Atkinson, & Berish, 2003). A recent model of preference construction, Query Theory (Johnson, Häubl, & Keinan, 2007), suggests that differences in inhibitory control should affect decision performance for a number of decision-making phenomena such as the endowment effect (Johnson, et al., 2007), temporal discounting (Lerner, Li, & Weber, 2011; Weber et al., 2007), default effects (Dinner, Johnson, Goldstein, & Liu, 2011), and attribute labeling (Hardisty, Johnson, & Weber, 2010). Inhibitory control also declines with age (Hasher, Zacks, & May, 1999; Salthouse, et al., 2003) and may therefore provide another obstacle to good decision-making in older adults.

2.2 Increasing Capabilities: Knowledge and Experience-Based Factors

Crystallized intelligence reflects a stable repository of knowledge acquired through experiences, culture, and education (Carroll, 1993; Cattell, 1971, 1987). Whereas fluid intelligence declines with age, crystallized intelligence seems to increase with age into the 60s and remains largely preserved thereafter (Horn & Cattell, 1967; Li, et al., 2004; Salthouse, 2004, 2006, 2010). Researchers have argued that crystallized intelligence is related to different components of wisdom, including taking multiple perspectives, allowing compromises, and recognizing the limits of one's knowledge (Grossmann, et al., 2010). The present study examines how this accumulated, experience-based knowledge influences decision-making. In particular, we investigate whether older adults' higher levels of crystallized intelligence can help offset their lower levels of fluid intelligence. Following standard practice (e.g., Friedman, et al., 2006; Hambrick, Salthouse, & Meinz, 1999; Mata, Schooler, & Rieskamp, 2007; Ratcliff, Thapar, & McKoon, 2010), we used measures of vocabulary and general knowledge to assess a global measure of crystallized intelligence rather than specific knowledge across different domains. Whereas past research has related domain-specific knowledge to domain-specific task performance, such as connecting vocabulary and general knowledge to crossword-puzzle solving

(Hambrick, et al., 1999), we treat these measures as domain-general indicators of crystallized intelligence and relate them to task performance across multiple domains.

2.3 Individual Differences in Decision Performance

There has been emerging interest in the relationship between cognitive capability and decision-making (Agarwal & Mazumder, 2010; Del Missier, Mäntylä, & Bruine de Bruin, 2011; Dohmen, Falk, Huffman, & Sunde, 2010; Shamosh & Gray, 2008) and in relating age differences in decision-making to age differences in cognitive capability (Bruine de Bruin, Parker, & Fischhoff, 2011; Hanoch, Wood, & Rice, 2007; Mata, et al., 2007; Mather, 2006; Peters, Hess, Vaestfjaell, & Auman, 2007). Most of this research distinguishes between deliberative and controlled processing (System 2) and implicit, automatic, and often affective processing (System 1), described in dual-process models of decision-making (Kahneman, 2003; Sloman, 1996). The argument goes that, as deliberative processes decline with age, implicit and automatic forms of knowledge, such as affect, become more important inputs into decisions (Mather, 2006; Peters, Finucane, MacGregor, & Slovic, 2000; Peters, et al., 2007). Researchers have argued that, due to an imbalance between deliberative and affective modes, older adults are less able to control the impact of automatic processing and might therefore be more susceptible to decision-making biases and marketing manipulations using affective appeals (Hess, McGee, Woodburn, & Bolstad, 1998; Hess, Waters, & Bolstad, 2000; Jacoby, 1999). However, relying on affective cues has also been shown to be useful in some decisions, like in the Iowa Gambling Task (Damasio, 1994). Indeed, relying on heuristics and affective cues can be efficient, for example when older adults rely on simpler search strategies and take less information into account before making decisions (Besedes, Deck, Sarangi, & Shor, 2010; Mata & Nunes, 2010; Mata, et al., 2007; Queen & Hess, 2010). In these cases, increased experience-based knowledge helps older adults make appropriate decisions without actively processing all the information.

Although many researchers have theorized about possible connections between changing cognitive processes and age differences in decision-making, few decision-making researchers

have empirically assessed cognitive capabilities (for exceptions, see Agarwal & Mazumder, 2010; Del Missier, et al., 2011; Dohmen, et al., 2010). Most papers in this domain examine only the effects of age on decision-making, with conflicting results: Some aspects of decision-making seem to worsen with age, including susceptibility to framing effects (Finucane, Mertz, Slovic, & Schmidt, 2005; Kim, Goldstein, Hasher, & Zacks, 2005), applying decision rules (Bruine de Bruin, Parker, & Fischhoff, 2007), making the optimal choice when the number of options increases (Besedes, et al., 2010), being overconfident (Crawford & Stankov, 1996), and risk averse across many domains (Dohmen et al., 2011). However, other research finds no age differences in susceptibility to framing (Mayhorn, Fisk, & Whittle, 2002; Roennlund, Karlsson, Laggnaess, Larsson, & Lindstroem, 2005), performance on the Iowa Gambling Task (Damasio, 1994), or the endowment effect (Kovalchik, Camerer, Grether, Plott, & Allman, 2005). Still other research finds that older adults are better at decision-making: They have more accurate evaluations of their own knowledge (Kovalchik, et al., 2005), are less affected by sunk costs (Strough, Mehta, McFall, & Schuller, 2008), and better at avoiding the influence of irrelevant alternatives (Kim & Hasher, 2005; Tentori, Osherson, Hasher, & May, 2001). Finally, some studies report a curvilinear relationship between age and decision-making: middle-aged adults are more patient (Read & Read, 2004) and make fewer financial mistakes (Agarwal, Driscoll, Gabaix, & Laibson, 2010) than either younger or older adults.

2.4 Compensating Capabilities, Decision-Making, and Aging

The combination of older adults' lower levels of fluid intelligence and inhibitory control but higher levels of crystallized intelligence gives rise to the intriguing possibility that both may mediate the effect of age on decision performance. We outline this multiple mediator model in Figure 1. Inhibitory control is omitted for simplicity because its effect is similar to that of fluid intelligence, but this framework can be generalized to additional mediators. As indicated by the positive paths on the right side of Figure 1, we hypothesize that both fluid and crystallized intelligence positively affect decision performance. However, based on abundant evidence of

opposing age trends in these two capabilities (indicated by positive and negative paths on the left of Figure 1), understanding the relationship between age and decision performance requires understanding multiple pathways to good decisions. Using a notation similar to that of standard mediation analysis, we refer to the multiplicative product of age relationships with fluid and crystallized intelligence and their relationships with decision-making as the *indirect effects* of age on decision-making ($a_i \times b_i$), as opposed to the *direct effect* (c') of age. The *total effect* (c) is then the relationship between age and decision-making when not controlling for mediators (by definition equal to the sum of the direct and indirect effects).

-----Figure 1-----

Figure 1 has several implications. First, because there are different age effects on fluid and crystallized intelligence, research needs to assess both capabilities. Examining the effect of one in the absence of the other results in omitted variable bias, which could either overstate or understate the effect of the examined variable. Second, the relationship between age and a given decision task will depend not only on the relationships of age with fluid and crystallized intelligence but also on the relative impact of crystallized and fluid intelligence on that task. If crystallized intelligence is a more important determinant of decision performance than fluid intelligence, we might expect older people to perform better. The opposite would be true for tasks where fluid intelligence plays a more important role.

Finally, Figure 1 suggests that relationships between age and performance may be masked by the opposing indirect effects of age via crystallized and fluid intelligence (Zhao, Lynch, & Chen, 2010). The total effect (c) of age on performance may appear to be zero, but there may nonetheless be indirect effects of age on performance via crystallized and fluid intelligence in opposite directions. Even when c is zero, the direct effect of age on performance (c') can be significant when controlling for mediators that add to a suppression effect. Our model therefore suggests that only looking for overall age effects (c) may be misleading and instead proposes a more general pattern of compensating capabilities.

Note that Figure 1 is not meant to suggest that crystallized intelligence increases as a

response to the loss of fluid intelligence with age. Instead, we assume that it increases independently as a function of acquiring experience. We thus use the word “compensate” differently than developmental psychologists and neuroscientists, who use it to describe compensatory reaction to a loss (Bäckman & Dixon, 1992; Baltes, 1997). Compensation in our model refers to the possibility that experience-based knowledge provides another pathway to good decision-making, one that allows for good performance when lower levels of fluid intelligence make reasoning-based pathways less successful. We expect that many tasks can be executed or “solved” via multiple pathways. For example, people can make intertemporal financial choices by calculating present values using interest rates; or they can rely on their experience with similar past intertemporal tradeoffs without making explicit calculations.

3. STUDY

3.1 Overview

To explore the potentially complex relationships between age, cognitive capabilities, and decision-making, we administered multiple measures for each variable in four waves of an online study to both younger and older adults. We analyzed the data using a standard two-step structural equation modeling (SEM) approach, first building separate measurement models for the cognitive capabilities and decision-making traits, and then analyzing the two measurement models together as functions of age. Since any measure of cognitive capability or decision-making can only measure the underlying trait with error, SEM allows us to assess the common variance shared by different measures of each underlying trait, giving us greater reliability than is possible with single measures. Although the entire model is of interest, we focus this paper on the role of the cognitive capabilities in mediating effects of age on decision performance.

To the best of our knowledge, our study is the first to combine multiple standard measures of fluid and crystallized intelligence from the cognitive aging literature with multiple measures of each of a number of important decision-making traits from the decision-making

literature and to show their relationships with age. In doing so, we extend the standard paradigm used by the cognitive aging literature to the decision-making domain. Collecting multiple measures allows us to explicitly model measurement error, something that most decision-making studies do not do, instead assuming perfectly reliable measures, which is rarely justified.

3.2 Selection of decision-making traits

We assessed decision performance on six different abilities suggested in the literature: Temporal discounting, loss aversion, anchoring, resistance to framing, debt literacy, and financial literacy. We focused on these tasks because they have implications for a wide range of real-world decisions with important financial and health consequences. We also hoped to establish whether performance on these tasks would reveal reliable individual differences across different versions of each and across time—i.e., whether observed differences in performance on each task reflect reliably-measurable, stable decision-making traits.

Temporal discounting is the degree to which people discount future gains and losses (for review, see Frederick, Loewenstein, & O'Donoghue, 2002) and has been found to be much higher, given the cost of borrowing, than would be expected for most people. This impatience has been found to affect decisions regarding saving and allocating assets (Angeletos, Laibson, Repetto, Tobacman, & Weinberg, 2001), borrowing with credit cards (Meier & Sprenger, 2010), walking away from underwater mortgages (Atlas, Johnson, & Payne, 2011), smoking and other addictive behavior (Bickel & Marsch, 2001; Khwaja, Silverman, & Sloan, 2007), and lifestyle choices related to obesity and exercise (Chabris, Laibson, Morris, Schuldt, & Taubinsky, 2008; Weller, Cook, Avsar, & Cox, 2008).

Loss aversion is the degree to which valuations of losses outweigh those of gains of the same magnitude (for review, see Tversky & Kahneman, 1991). Loss aversion has been shown to lead investment bankers to focus on avoiding losses rather than making gains (Willman, Fenton-O'Creevy, Nicholson, & Soane, 2002), small investors to hold onto losing stocks too long (Odean, 1998), home owners to set higher selling prices (Genesove & Mayer, 2001), and

consumers to respond asymmetrically to price changes (Hardie, Johnson, & Fader, 1993).

Anchoring is the tendency for consideration of one number to influence subsequent numerical judgments (for review, see Chapman & Johnson, 2002) and has been shown to affect consumers' perception of product values and purchase quantities (Ariely, Loewenstein, & Prelec, 2003; D. Green, Jacowitz, Kahneman, & McFadden, 1998; Nunes & Boatwright, 2004), judgments of buying and selling prices (Simonson & Drolet, 2004), real estate appraisals (Northcraft & Neale, 1987), purchase quantities (Wansink, Kent, & Hoch, 1998), and credit card repayment amounts (Stewart, 2009).

Resistance to framing. Following Bruine de Bruin and colleagues (2007), we also attempted to measure people's tendency to be affected by normatively irrelevant variation in how problems are presented, e.g., whether options are framed as gains versus losses (Tversky & Kahneman, 1981). Option framing has been shown to affect decisions regarding alternative cancer treatments (McNeil, Pauker, Sox Jr, & Tversky, 1982), insurance (Johnson, Hershey, Meszaros, & Kunreuther, 1993), health behaviors (Rothman & Salovey, 1997), and negotiations (Neale & Bazerman, 1985).

Financial literacy and debt literacy refer to the ability to understand financial information and decisions (Lusardi & Mitchell, 2007), and the ability to make decisions regarding debt contracts and understand interest rates (Lusardi & Tufano, 2009), respectively. Although we are mostly interested in more domain-general decision performance characteristics, we also examined these two domain-specific measures due to their obvious impact on real-world decisions. Financial and debt literacy are increasingly important as consumers are faced with more difficult economic decisions. For retirement savings as an example, the increase in self-managed defined-contribution plans (e.g., 401K) presents challenges and opportunities not present in previous defined-benefit plans (e.g., pensions). People with greater financial literacy are more likely to choose better mutual funds (Hastings & Tejada-Ashton, 2008), accumulate and manage wealth effectively (Hilgert, Hogarth, & Beverly, 2003), and plan for retirement

(Lusardi & Mitchell, 2006, 2007, 2009), whereas people with better debt literacy tend to have lower borrowing costs (Lusardi & Tufano, 2009).

3.3 Methods

3.3.1 Sample and Procedure

Younger adults (age range: 18-29, $M = 24.76$, $Median = 25$, $SD = 2.91$) and older adults (age range: 60-82, $M = 66.39$, $Median = 65$, $SD = 4.93$) from the Columbia University Center for Decision Sciences' Virtual Lab Panel completed all four waves of a web-based survey consisting of cognitive, decision-making, and demographic measures. This panel consists of 55,000 people who have agreed to participate in psychological and decision research for financial compensation. We selected participants from the panel who fell within each specified age range and were U.S. residents. Participants received email invitations between February and June 2009 (waves 1-3) and between June and September 2010 (wave 4). The last wave was delayed by a year to assess the reliability of the decision measures. Only participants who completed each wave received invitations to subsequent waves. Participants were paid \$25 upon completion of the first three waves and \$15 for the fourth via their choice of PayPal payments or Amazon.com gift certificates. In addition, three of the decision-making measures were incentive-compatible.²

-----Table 1-----

In total, 632 American participants ($N_{\text{young}} = 332$, $N_{\text{old}} = 300$) completed the first wave, 562 (11.1% dropout) completed the second, 516 (8.2% dropout) completed the third, and 336 (34.9% dropout) completed the fourth, for a total dropout rate of 46.8%. The dropout rates were low considering that more than a year elapsed between the first and fourth waves (Reips, 2002). Importantly, there was no difference in dropout between younger (47.9%) and older groups (45.7%). No demographic, cognitive, or decision-making measure predicted whether participants dropped out, after making a Bonferroni correction for multiple comparisons, suggesting that we

² Intertemporal choices in the first, third, and fourth waves were played for real money for 1 in 50 participants. These additional payments ranged from \$20 to \$110 depending on participants' choices.

do not need to account for selective attrition.

Our final sample consisted of 173 younger and 163 older participants. Table 1 shows the socioeconomic distributions by age group. Older participants were somewhat more educated than younger participants, with a higher percentage attaining post-graduate degrees (26.4% vs. 15.0%, $\chi^2(1) = 6.63, p < .01$) and more years of education on average (15.4 vs. 14.8, $t = 2.30, p < .05$). However, they had about the same level of household incomes (assuming median in each income range, $M_{old} = \$58.6K$ and $M_{young} = \$61.1K, t = .58, ns$). Household income was positively correlated with years of education ($r = .22, p < .0001$).

3.4 Tasks and Measures

3.4.1 Cognitive measures

Table 2 lists the 11 standard cognitive tasks designed to measure fluid intelligence, crystallized intelligence, and inhibitory control. These tasks were distributed across all four waves and interspersed with the decision-making measures and each other. Details on all measures can be found in the supporting online materials.

Fluid intelligence. Among our five measures of fluid intelligence, the most widely used is the *Raven's Progressive Matrices* task (Raven, 1962), a non-verbal test of inductive and analytic reasoning. Our version (Salthouse, Pink, & Tucker-Drop) asked participants to determine which option correctly filled in the missing cell for each of 18 3×3 matrices. We also included two other standard measures of inductive and reasoning ability: *Letter Sets* (Ekstrom, French, Harman, & Dermen, 1976; Salthouse, et al., 2008; Thurstone, 1962) asked participants which of five letter sets (e.g., NOPQ, DEFL, ABCD, HIJK, and UVWX) did not fit the rule that the other four fit (e.g., DEFL). *Number Series* (Thurstone, 1962) asked participants to fill in the blank in six series of numbers (e.g., 23, 26, 30, 35, ___) in an adaptive two-block version (McArdle & Woodcock, 2009).

-----Table 2-----

Finally, we included two individual difference measures commonly used in decision

research that seem to measure fluid intelligence: The *Cognitive Reflection Test* (CRT; Frederick, 2005; Frederick, et al., 2002) consists of three math questions that yield quick but incorrect first responses. *Numeracy* (Lipkus, Samsa, & Rimer, 2001) tests the ability to understand probability and mathematical concepts. The CRT has been found to have a positive relationship with general cognitive function as well as time and risk preferences (Frederick, 2005) and research has indicated that people with higher numeracy have better comprehension of comparative information (Hibbard, Peters, Dixon, & Tusler, 2007) and better SAT scores (Peters et al., 2006).

Crystallized intelligence. We measured crystallized intelligence with three tasks. The *Shipley Vocabulary* task (Zachary, 1986) is a 40-item multiple-choice synonym vocabulary test, and our version was adapted from CREATE's Common Core Battery of Measures (Czaja, Charness, Dijkstra, et al., 2006; Czaja, Charness, Fisk, et al., 2006). Similarly, *Antonym Vocabulary* (Salthouse, 1993) measured vocabulary using 10 multiple-choice antonym selection items. Finally, the WAIS-III *Information Task* (Wechsler, 1997), as adapted by CREATE (Czaja, Charness, Dijkstra, et al., 2006; Czaja, Charness, Fisk, et al., 2006), asked participants 28 open-ended general-knowledge questions about events, objects, places, and people.

Inhibitory control. We measured inhibitory control using three tasks developed for the web by Lumos Labs (www.lumosity.com). The *Stroop Task* (Stroop, 1935) measured differences in reaction times between trials in which the name of a color word matched or did not match its font color. Similarly, the *Flanker Task* (Eriksen & Eriksen, 1974) measured differences in reaction times between trials in which the orientation of the central item was the same or different from the orientation of the flanking items. Finally, *Spatial 1-back* (Kane, Conway, Miura, & Colflesh, 2007) measured participants' reaction times in reporting whether the spatial position of a red ball in each trial was the same as its position in the previous trial. Although participants completed two trials of each inhibitory control task, we used their average performance due to the high reliability between the two measures.

3.4.2 Decision performance measures

We included three to five measures of each decision-making trait, again distributed

across all four waves (see Table 2) and interspersed with other measures. Different measures of the same task were presented in fully counterbalanced order within each wave to control for order effects. Since no order or item effects were found for any decision-making measure, they will not be discussed any further. Importantly, performance on each task can be classified by the degree to which it conforms to normative, rational-economic models, as described below.

Temporal discounting was measured with five choice titrators (L. Green, Fry, & Myerson, 1994). Three of the titrators presented participants with a series of choices between a fixed smaller gift certificate today (\$60, \$55, and \$100) and varying amounts of a larger gift certificate at a delayed time point (4, 3, and 12 months). The remaining titrators instead fixed the larger, future gift certificate (\$75 and \$115 in 3 months) and varied the amount of the gift certificate today, thus allowing participants to accelerate payment at the cost of receiving less money. The dependent variable for each titrator was the participant's exponential annual discount factor (which can theoretically range from 0 to 1) as implied by the midpoint between preferring the earlier versus later payments (i.e., the indifference point). Using hyperbolic discounting rates gives similar results. Because nearly all participants revealed impatience levels that appeared too high relative to the economic standard (i.e., the interest rate on available loans and credit cards), larger discount factors (closer to one), indicating more patient preferences, were coded as better.

Loss aversion was also measured with five choice titrators. Each titrator presented participants with a series of choices indicating willingness to play each of a series of binary gambles with a 50% chance of winning some fixed amount (\$6 or \$20) and a 50% chance of losing some varying amount (between \$0.50 to \$7 in \$0.50 increments or between \$2 to \$24 in \$2 increments). Two of the titrators in the first wave were repeated in the fourth wave one year later without any change. We calculated loss aversion coefficients by dividing the gain amount by the loss amount at the indifference point (i.e., midpoint between where the participant switches from willing to play the gamble to not willing). Because a loss aversion coefficient equal to one is economically rational and anything else irrational (93.2% of responses yielded

some degree of loss aversion), coefficients were reverse-coded so that larger values were better.

Anchoring was measured with two sets of three numerical estimation questions each (e.g., distance between New York and Cairo). In each set, one question was preceded by a high anchor question (e.g., “Is the distance between New York and Cairo less than or greater than 11300 miles?”), one by a low anchor (e.g., 1400 miles), and one by no anchor (i.e., just the estimate). Questions were counterbalanced with anchor condition in a Latin squares design. We calculated z-scored estimates by pooling responses across anchor conditions within question. We used the z-scored estimates for the two questions preceded by low anchors and reverse-coded, z-scored estimates for the two questions preceded by high anchors as our four dependent measures. Higher z-scores, corresponding to being less influenced by anchors, were coded as better.

Resistance to framing was measured with four scenarios offering choices between a risky option and a sure option, varying the framing of the options as gains or losses (Tversky & Kahneman, 1981). We used the classic Asian disease problem (e.g., number of lives saved or lost), as well as variants about potential layoffs (e.g., factories kept open or shut down), drought (e.g., acres of crops saved or lost), and bankruptcy (e.g., investments saved or lost). Each participant saw either the gain or loss version of each scenario, with one of each in the first and fourth waves. Resistance to framing was determined by whether choices for the pair of gain and loss scenarios in each wave were both risk-seeking or both risk-averse (coded as 1) or were inconsistent because influenced by the gain-loss (coded as 0), with higher values being better.

Financial and debt literacy were measured using three financial literacy questions (Lusardi & Mitchell, 2006) designed to assess knowledge of fundamental economic concepts, and three debt literacy questions (Lusardi & Tufano, 2009) designed to assess knowledge of compound interest and credit card debt. Each answer was coded as correct (1) or not (0), with higher values being better.

4 RESULTS

4.1 Preliminary Analysis

We cleaned the data set using preplanned, standard procedures, removing non-monotonic responses from the temporal discounting (1.2%) and loss aversion (1.9%) titrators, since they represent participants who did not understand or attend to those tasks. There were no age differences in the proportion of non-monotonic titrator responses. We also removed exactly correct answers for the anchoring questions (4.3%), since anchors have no chance of affecting people who actively know the correct amounts.³ We then log-transformed all skewed variables ($|\text{skew}| > .8$), standardized all variables, and removed outliers beyond 3.5 standard deviations (7 data points in total). Importantly, we coded all variables so that higher scores corresponded to better performance (note, however, that Table 3 shows the original coding for the inhibitory control measures, such that smaller reaction time differences are better).

4.2 Overview

We followed procedures standard to the cognitive aging literature (e.g., Del Missier, et al., 2011; Lindenberger, et al., 1993; Salthouse, et al., 2003) for analyzing the relationships between age, cognitive capabilities, and other abilities. We begin by reporting mean age differences for all measures and their correlations. We then characterize the cognitive capabilities measurement model by testing for convergent and discriminant validity, and showing measurement invariance between younger and older groups. We do the same for the decision-making variables and then combine them with the cognitive capabilities measurement model and age in a structural equation model to test the compensating capabilities hypothesis. We ran all analyses in Mplus (Muthén & Muthén, 2010) using both standard and bootstrapped estimation procedures (Preacher & Hayes, 2008; Shrout & Bolger, 2002). The bootstrapped analyses used 10,000 bootstrapped samples and constructed confidence intervals for each parameter using the

³ A substantial number of participants knew how many bones were in the adult human body (11.9%) and the year Beethoven was born (5.7%). Younger participants gave more correct answers (6.1%) than older participants (2.5%). Including these exact answers does not substantially impact results.

bootstrapped distributions. We report the significance levels for the bootstrapped analyses corresponding to the widest confidence interval not including zero, but standard analyses found similar results.

We used two standard indices to evaluate model fit. Root mean square error of approximation (RMSEA) is a measure of the difference between predicted and observed covariances, with values under .05 considered good and under .08 considered adequate (Browne & Cudeck, 1993; Steiger, 1990). The Bentler comparative fit index (CFI) indicates the relative improvement of the hypothesized model over the null or independent model (in which all variables are unrelated). Values of CFI above .90 are considered adequate and above .95 good (Hu & Bentler, 1999). Both indices are penalized for model complexity and thus favor models that can more parsimoniously explain the observed covariance patterns. We also report the model chi-square for purposes of model comparison but do not interpret its significance due to our large sample size (Kline, 2010).

4.3 Step 1: Cognitive capabilities measurement model

-----Table 3-----

Table 3 shows the mean scores for each cognitive measure for younger and older participants, as well as the pairwise correlations between the measures across both age groups. Different measures for each cognitive factor were significantly correlated with one another ($r_s = .27$ to $.51$ for fluid intelligence, $.51$ to $.65$ for crystallized intelligence, and $.52$ to $.67$ for inhibitory control; all $p_s < .001$). To determine the validity of the cognitive capabilities measurement model, we conducted a confirmatory factor analysis (CFA) on the cognitive measures. As seen in the factor loadings in Table 4 and Figure 2, the three-factor model consisting of fluid intelligence (G_f), crystallized intelligence (G_c), and inhibitory control (IC) factors showed convergent validity, with significant loadings for all cognitive measures on their hypothesized factors. The model showed reasonable fit to the data with a CFI of .94 and a

RMSEA of .076.⁴ Importantly, fluid intelligence was positively correlated with crystallized intelligence and inhibitory control (see Table 4), both across all participants and within each age group. Crystallized intelligence was negatively correlated with inhibitory control across all participants, but this correlation was slightly positive within each age group.

-----Table 4-----

Table 4 provides the factor loadings and fit statistics for two standard comparison models: (1) a one-factor model; and (2) a three-factor model in which the factors are forced to be uncorrelated. As Table 4 shows, both alternative models fit the data significantly less well than the hypothesized three-factor model with correlated factors (χ^2 difference tests, $\chi^2(3) = 163.17$ and 645.26 , respectively, both $p < .0001$). Therefore, even in the presence of significant inter-factor correlations, the hypothesized measurement model demonstrates discriminant validity.

-----Figure 2-----

4.3.1 Age differences for cognitive factors

Table 3 shows that younger participants were significantly better at all measures of fluid intelligence and inhibitory control (all $t_s > 11$, all $p_s < .0001$) but significantly worse at all measures of crystallized intelligence (all $t_s > 3.78$, all $p_s < .001$). Relative to younger participants' factor scores, older participants' factor scores were significantly lower on fluid intelligence (path coefficient on "old" variable: $\beta = -.69$, bootstrapped $p < .0001$) and inhibitory control ($\beta = -1.29$, $p < .0001$), but significantly higher for crystallized intelligence ($\beta = .72$, $p < .0001$). Importantly, the similar magnitudes of age effects on fluid and crystallized intelligence in opposite directions leaves open the possibility that older participants' higher levels of crystallized intelligence offset their lower levels of fluid intelligence.

4.3.2 Measurement invariance

Given the age differences on the cognitive factors, it is important to test for measurement

⁴ Note that all models in Table 4 allowed for residual correlation between CRT and Numeracy. These measures have similar mathematical components so it is reasonable that they share unexplained variance. Omitting these residual correlations affects the fit of the model but not subsequent results.

invariance across younger and older participants (Kline, 2010; Vandenberg & Lance, 2000), i.e., whether the cognitive tasks measure the same underlying factors in the same ways for both samples. We tested for factor invariance using multiple-group CFA, which fits the measurement model simultaneously to the data from the younger and older groups. Table 5 shows the fit indices for successively more restrictive models. Model M1 specifies the same measurement model for both age groups, but all parameters were freely estimated within each group. M1 fit the data fairly well (RMSEA = .057, CFI = .950), suggesting that the measurement model satisfies configural invariance (Kline, 2010).

With one exception, our proposed factor structure demonstrated metric invariance. Model M2, which restricts the factor loadings to be equal across age groups for each cognitive task, did not fit the data as well as M1, and a χ^2 difference test verified the difference in model fits ($\Delta\chi^2(8) = 25.01, p < .01$). This discrepancy appeared to be due to a difference in the loading of Raven's Progressive Matrices. An alternative model M2', with equal factor loadings on all but Raven's Progressive Matrices, did not fit the data significantly differently from model M1 ($\Delta\chi^2(7) = 13.79, p = .06$), suggesting that the reliability of the Raven's Progressive Matrices task was different between younger and older groups. However, relaxing this restriction did not change the results of subsequent analyses, so the cognitive capabilities measurement model satisfies complete metric invariance.

Model M3, in which factor variances and covariances were restricted to be equal across age groups, fit about as well as model M2' ($\Delta\chi^2(4) = 3.19, ns$), suggesting that the factor variances and covariances are equivalent across age groups. Finally, Model M4, in which means for each cognitive task were restricted to be equal across age groups, provided much worse fit to the data than Model M3 ($\Delta\chi^2(11) = 383.41, p < .0001$), as expected, meaning that younger and older participants performed significantly differently on the cognitive tasks.

-----Table 5-----

4.4 Step 2: Decision-making measurement model

Table 6 shows the mean scores for each decision performance measure for each age group, as well as the correlations between measures within a given task category. Different measures for temporal discounting ($r_s = .33$ to $.62$, all $p_s < .0001$), loss aversion ($r_s = .41$ to $.82$, all $p_s < .0001$), financial literacy (Spearman $r_s = .07$ to $.40$, all $p_s < .001$ except for correlations with the third question), and debt literacy (Spearman $r_s = .15$ to $.33$, all $p_s < .01$) were significantly correlated with one another. However, different measures for resistance to framing ($r = -.05$, ns) and anchoring ($r_s = 0$ to $.15$, two $p_s < .05$ and others ns) were not significantly correlated, suggesting that neither reliably measured an underlying decision-making trait. As a result, we dropped anchoring and resistance to framing in all subsequent analyses.

-----Table 6-----

We next conducted a CFA on the remaining, reliable decision-making measures for temporal discounting, loss aversion, financial literacy, and debt literacy. As seen in the factor loadings in Figure 3 and Table 7, all four decision-making factors showed convergent validity. The four-factor model showed good fit with a RMSEA of $.041$ and a CFI of $.939$.⁵ Table 7 also shows significant correlations between the temporal discounting, financial literacy, and debt literacy factors ($r_s = .39$ to $.75$, all $p < .001$), whereas loss aversion was only correlated with debt literacy ($r = .25$, $p < .01$).⁶

-----Figure 3-----

-----Table 7-----

4.4.1 Age differences for decision-making factors

Table 6 shows that, although not all age differences in performance on the decision-

⁵ The decision-making factor model allows residual correlations between the first, second and third temporal discounting tasks and between the first and second loss aversion tasks. Each pair of measures used nearly identical methods so it is reasonable that they share unexplained variance. Omitting these residual correlations affects model fit but not subsequent results.

⁶ The correlation between financial and debt literacy ($r = .75$, $p < .001$) raised concerns of potential multicollinearity. However, when we compared the four-factor model with a three-factor model in which financial and debt literacy were combined into a single factor, model fits were worse (RMSEA = $.041$, CFI = $.938$). A χ^2 difference test revealed that the three-factor model fit significantly worse than the four-factor model, $\chi^2(3) = 9.42$, $p = .02$.

making tasks were significant, older participants tended to make better decisions. They were significantly more accurate on the financial and debt literacy questions and somewhat more patient on the temporal discounting questions. Relative to younger participants' factor scores, older participants' factor scores were significantly higher on financial literacy (path coefficient on "old" variable: $\beta = .83$, bootstrapped $p < .0001$) and debt literacy ($\beta = .28$, $p < .01$), marginally higher for temporal discounting ($\beta = .11$, $p < .10$), and no different for loss aversion ($\beta = .08$, *ns*). Although older participants in our study were generally better decision-makers than younger participants and never worse, we note that these main effects may shroud the underlying relationships between changing cognitive ability and decision-making, which we explore below.

As with the cognitive measurement model, we tested whether the decision-making tasks measured the same underlying factors for both younger and older participants using multiple-group CFA. Table 8 shows model fits and difference tests for each step of this procedure. Models DM1 and DM2 showed that the decision-making factors satisfy configural invariance and metric invariance, respectively. Model DM3 showed that factor covariances were equivalent across age groups. Model DM4 and DM4' showed that factor variances were equivalent across age groups for all decision-making factors except for financial literacy. In short, the decision-making tasks measured the same underlying decision-making factors for younger and older groups, with the minor exception that financial literacy was measured with more noise in the older group.

-----Table 8-----

4.5 Step 3: Relationship between cognitive capabilities, decision performance, and age

Having established divergent and convergent validity and reasonable measurement invariance for both the cognitive capabilities and decision performance factors, we now examine the relationships between these factors and age. First, we explored simple relationships between cognitive capabilities and decision performance by combining the cognitive and decision-making models and adding paths between all decision-making factors to all cognitive factors in a structural equation model (SEM). An SEM is a combination of path analysis with factor analysis,

concurrently estimating four multiple regressions of the decision-making factors on the cognitive capability factors while simultaneously estimating the factor structures for all cognitive and decision-making variables. In this and all subsequent SEM analyses, we included demographic controls for gender, education, and income in order to remove any possible confounding effects due to underlying demographic differences between the younger and older groups. Models without demographic controls were qualitatively similar, although loss aversion results were somewhat less significant.

-----Table 9-----

Table 9 shows that, as predicted, temporal discounting, financial literacy, and debt literacy were all positively related to both fluid and crystallized intelligence. Loss aversion, on the other hand, was not related to either fluid intelligence or crystallized intelligence but was negatively related to inhibitory control. Financial literacy was also negatively related to inhibitory control. We provide some possible explanations for these unpredicted relationships below, when discussing the mediation results.

4.5.1 Mediation analysis

In the final stage of analysis, we used the multiple mediation approach outlined in Figure 1 to test whether the cognitive capabilities could help explain the observed age differences in decision performance. Importantly, we were able to simultaneously estimate and test all direct and indirect effects within a single SEM framework. This relatively new way to conduct mediation analyses allows us to estimate indirect effects even if the total effect of age on a given factor is not significant (Zhao, et al., 2010). That is, cognitive capabilities (e.g., inhibitory control) can be significant mediators of decision performance (e.g., loss aversion) even if there is no significant total effect of age.

Table 10 shows the standardized coefficients of the relevant paths in the SEM mediation analysis. Recall that the total effect of age (c in Figure 1) is equivalent to the path from age to the decision-making factor in a model without mediators. The significance of an indirect effect of age tests whether a given cognitive capability mediates the effect of age on that decision-making

factor; it is equivalent to the product ($a_i \times b_i$) of the path from age to the cognitive capability (a_i) and the path from the cognitive capability to the decision-making factor (b_i). Finally, the direct effect of age (c') is the path from age to the decision-making factor after all indirect effects have been accounted for in the model.

-----Table 10-----

Recall that Figure 1 provided the framework for our compensating capabilities hypothesis of age differences in decision performance. In this model, part of any age difference is due to competing and possibly compensating indirect effects of age via fluid and crystallized intelligence, where older participants' well-documented lower levels of fluid intelligence may be offset by their higher levels of crystallized intelligence. In Table 10, compensation would be shown by fluid and crystallized intelligence having negative and positive indirect effects, respectively. This pattern, and in particular the similar magnitudes and opposite direction of the indirect effects, is evident for three of the four decision-making factors. Looking, for example, at temporal discounting in standard mediation terms, fluid intelligence suppressed the relationship between age and discounting, whereas crystallized intelligence mediated it. In this case, the opposing indirect effects of fluid and crystallized intelligence perfectly offset each other. That is, older participants' higher levels of crystallized intelligence compensated for their lower levels of fluid intelligence, preventing them from making more impatient intertemporal choices than their lower levels of fluid intelligence would otherwise predict.

For financial literacy and debt literacy as well, older participants' higher levels of crystallized intelligence offset their lower levels of fluid intelligence, fully for financial literacy and partially for debt literacy. However, the compensation pattern for both types of literacy was further complicated by the presence of inhibitory control as another marginally negative mediator. That is, although lower levels of fluid intelligence were balanced by higher levels of crystallized intelligence, older participants were additionally worse at financial and debt literacy due to their lower levels of inhibitory control. As a result, the direct effects of age on financial and debt literacy in the mediated model were actually higher than their respective total age

effects. In other words, the net mediating effect of the cognitive factors was to suppress positive age effects. The advantage older participants hold over younger participants in financial and debt literacy would be even higher were it not for older participants' lower levels of fluid intelligence and inhibitory control.

Finally, as anticipated by the simple SEM results, we found that compensating capabilities did not explain age relationships with loss aversion. In fact, neither fluid nor crystallized intelligence was correlated with loss aversion. Instead, inhibitory control served as a marginally positive mediator of the effect of age on loss aversion. This result is particularly counterintuitive because this positive indirect effect is the product of two negative effects—namely, older participants' choices were less loss averse precisely because they have worse inhibitory control. The fact that getting worse at something may in fact contribute to better decisions suggests that specific features of the loss aversion measures may be responsible. One possibility is the fact that all five loss titration tasks started with series of fairly attractive gambles with much greater gains than losses (e.g., even odds of losing \$0.50 or gaining \$6). Saying “yes” to a number of these gambles may make it the prepotent response to continue choosing “yes” for subsequent gambles with larger potential losses (e.g., even odds of losing \$6 or gaining \$6). A failure to inhibit prepotent responses here would cause participants to act as if they were behaving less loss averse. Further research on this relationship should utilize different formats to measure loss aversion.

4.6 Summary of results

In sum, our older participants performed as well as or better than younger participants on all measured decision-making tasks. We found that fluid intelligence, crystallized intelligence, and inhibitory control partially mediated the effect of age on performance for four stable, trait-like decision-making tasks. In particular, we found support for the compensating capabilities hypothesis of the effect of age on temporal discounting, financial literacy, and debt literacy: Older participants' higher levels of crystallized intelligence offset their lower levels of fluid

intelligence. Inhibitory control acted as an additional negative mediator of age effects on financial literacy and debt literacy, so that the direct effects of age were magnified after controlling for all three mediating cognitive capabilities. This net suppression effect suggests that there is some component of these decision-making traits not captured by our set of cognitive capability measures, possibly domain-specific financial knowledge as opposed to the measured domain-general construct of crystallized intelligence. We discuss this further below.

5. DISCUSSION

The average age of the world's population is rising rapidly, and the proportion of people older than 60 years will continue growing until at least 2050 (United Nations, 2002). Understanding how and how well older adults make decisions is crucial because they are faced with an increasing number of important choices related to their retirement finances and health care (Mather, 2006; Peters, et al., 2000; Peters, et al., 2007; United Nations, 2002). Furthermore, as new laws increase the minimum retirement age, people remain professionally active later in life, with older adults holding many key leadership roles. Given their influence over the economy and society, this paper set out to explore whether older adults are better or worse decision-makers than younger adults. We hypothesized and found that any predictions of expected age differences in decision performance would be related to the competing contributions of fluid and crystallized intelligence to the task.

5.1 Cognitive Capabilities and Decision Performance

Our age effects on cognitive capabilities firmly replicated well-established findings in cognitive aging: Older participants had significantly worse fluid intelligence and inhibitory control but significantly better crystallized intelligence than younger participants (Salthouse, 2004, 2010). We also found relationships between the cognitive capabilities and decision performance consistent with previous research. Both fluid and crystallized intelligence were positively related to patience in temporal discounting as well as financial and debt literacy.

The positive relationship between intelligence and patience in temporal discounting is consistent with previous research (Dohmen, et al., 2010; Shamosh & Gray, 2008). In particular, de Wit and colleagues (2007) found that patience was positively related to both fluid and crystallized intelligence. Other studies, gathered as part of large national panels, also found positive relationships between financial literacy and measures of fluid intelligence such as numeracy and number series (Banks, O’Dea, & Oldfield, 2010; McArdle, Smith, & Willis, 2009; Smith, McArdle, & Willis, 2010), but did not include measures of crystallized intelligence. However, some researchers have argued that financial literacy should be related to crystallized intelligence and found positive relationships with educational attainment (Delavande, Rohwedder, & Willis, 2008; Lusardi & Mitchell, 2011). We note that the positive relationship we found between crystallized intelligence and decision performance persisted even though we controlled for education.

The opposing age differences for fluid and crystallized intelligence with age, together with their positive relationships with decision performance, provided the underpinnings for our compensating capabilities hypothesis of how age differences in cognitive capabilities mediate age differences in decision performance, which was supported for temporal discounting, financial literacy, and debt literacy. For these decision tasks, lower levels of fluid intelligence in older adults were related to lower decision performance, but higher levels of crystallized intelligence offset this negative age effect. For temporal discounting, crystallized intelligence perfectly offset differences in fluid intelligence, leading to no net age effect. For financial and debt literacy, higher levels of crystallized intelligence were not enough to fully offset lower levels of both fluid intelligence and inhibitory control, both of which had negative relationships with performance.

5.2 Age Differences in Decision Performance

Our older participants showed equal or better decision performance than our younger participants, exhibiting greater patience in intertemporal choices and better financial and debt

literacy. Older participants were also somewhat less loss averse, although this result did not reach standard levels of significance.

Our results on temporal discounting are in line with other studies showing that older adults are more patient (L. Green, et al., 1994; Reimers, Maylor, Stewart, & Chater, 2009). However, other researchers (Read & Read, 2004) have found an inverted U-shaped relationship between age and impatience: Older participants (mean age of 75) were the least patient, while middle-aged participants (mean age of 44) were more patient than both older and younger participants (mean age of 25). Similarly, Souza and Seymour (2003) found that patience increased until middle age before dropping in old age and Trostel and Taylor (2001) found that older participants (mean age of 80) were less patient. These discrepancies in results may be due to the average age of the older participants in each study. For instance, Green and colleagues' (1994) older participants were close in age to their middle-aged participants, and Reimers and colleagues (2009) did not have meaningful data for people above 65. This argument also holds for the current study, in which the mean age for older participants was only 66. Thus, our older participants may be closer to the middle-aged participants of other studies in terms of their discounting behavior. We discuss in the next section that our compensating capabilities model predicts an inverse-U-shaped relationship for discounting over the life span.

Whereas nobody before us has explicitly explore age differences in loss aversion as a function of cognitive skills, age differences have been studied on related tasks in which loss aversion may play a role. For example, most studies of the Iowa gambling task (Kovalchik, et al., 2005; MacPherson, Phillips, & Della Sala, 2002; Wood, Busemeyer, Kolling, Cox, & Davis, 2005), framing effects (Mayhorn, et al., 2002; Roennlund, et al., 2005), and the endowment effect (Kovalchik et al., 2005) find no age-related differences, consistent with the present study's finding that older participants were insignificantly less loss averse.

Our finding that older participants were better at financial and debt literacy are consistent with research by Delavande and colleagues (2008). However, other research has found a negative relationship between debt literacy and age (Lusardi & Tufano, 2009) and an inverted U-

shape relationship between financial literacy and age (Lusardi & Mitchell, 2011). These conflicting results are most likely due to differences between samples, and we describe below how the underlying compensating capabilities hypothesis can explain these ostensibly contradictory results as well.

5.2.1 Decision Performance over the Life Span

As mentioned above as a possible explanation for discrepancies among findings about decision performance of older adults (with different degrees of elderliness), the compensating capabilities hypothesis makes predictions for decision performance across the life span. Even though our study (in which we examined two discrete age ranges, omitting participants aged 30 to 59, to increase the power of our analysis) does not allow us to trace decision performance across the *entire* life span, others have examined differences in cognitive capabilities across the life span. Because crystallized intelligence tends to plateau while fluid intelligence is even lower for adults aged 70 and above (Salthouse, 2004, 2010), compensating capabilities suggests that the relationship between age and decision performance will be characterized by a single-peaked function reminiscent of Simonton's (1997) career productivity curve. The exact nature of this function will depend on both the relative importance of crystallized and fluid intelligence to the task, as well as their levels at each age.

We can make rough extrapolations to the unstudied age ranges if we assume, supported by our data, that the roles of fluid and crystallized capabilities remain constant across the life span. Our compensating capabilities hypothesis suggests that crystallized intelligence will not be able to protect adults from the effects of further declines in fluid intelligence; consequently, decision performance may potentially decline for adults aged 70 and above. Figure 4 presents an approximate picture, using our estimated relationships between age, cognitive capability, and decision performance on temporal discounting and financial and debt literacy, and extrapolating to other ages using Salthouse's (2004) assessments of the levels of fluid and crystallized intelligence.

Importantly, an inverse-U-shaped relationship with age is evident for all three decision

tasks, with peaks in the mid-to-late 50s. This shape is consistent with the age pattern other research has found in various domains (Read & Read, 2004; Simonton, 1997). Agarwal and colleagues (2010) hypothesized such a pattern for financial decision-making over the life span and found support across 10 different domains using data from nationally-representative polls. Whereas the representativeness of their data strengthens the external validity of their findings, they did not measure any cognitive capabilities. Therefore, their work is consistent with the compensating capabilities hypothesis, but neither they nor other researchers have previously related these cognitive capabilities to decision performance in different age groups

-----Figure 4-----

5.2.2 *Sample Comparison*

Besides differences in the age ranges of our older participants, our sample may differ from those in other studies in other ways, perhaps due to selection effects that come with web-based studies. For example, our older participants may on average have more years of education, which has been linked to higher scores on cognitive tests (e.g., Ceci & Williams, 1997; Salthouse, 2010). Although our goal was to test the compensating capabilities model, we can nonetheless evaluate our participant sample relative to samples used by other researchers in aging.

Comparisons of our web-based older participants to similarly aged participants from the Center for Research and Education on Aging and Technology Enhancement (CREATE) participant pool suggest that there was no difference in the levels of education (Baldassi, Weber, Johnson, Czaja, & Nair, 2010), while older participants from Virginia Cognitive Aging Project (VCAP) were slightly more educated (16.2 years of education vs. 15.4; Salthouse, personal communication, December 28, 2011). Both older and younger participants in our study performed worse than similarly aged VCAP participants on Raven's Progressive Matrices and Letter Set tasks, but there were no interactions between sample and age group. Similarly, comparisons of performance on four fluid and crystallized tests to identical in-person tests at CREATE found some mean differences in performance between our web-based participants and

their offline participants, but again none of these differences interacted with age (Baldassi, et al., 2010). Finally, we screened 93 (57%) older participants using the Telephone Interview of Cognitive Status (TICS), finding that 90% of the older adults tested non-impaired and 10% ambiguous, and nobody tested either mildly or severely impaired.

5.3 What exactly offsets age-related declines?

Although our results indicate that crystallized intelligence is the cognitive capability older adults have that helps offset their lower levels of other capabilities, our measures of crystallized intelligence may not be the whole story. Recall that we assessed crystallized intelligence using two tasks that measured vocabulary and one that measured general knowledge. How does knowing the definition of “corpulent” or the identity of Catherine the Great contribute to greater patience in intertemporal choice? Although knowledge of this sort may affect performance on linguistic tests or crossword puzzles (Hambrick et al., 1999), it seems unlikely that it directly affects decision performance in tasks such as intertemporal choices and financial and debt literacy. However, vocabulary skill and general knowledge may nonetheless be a proxy for domain-specific knowledge, experience, and expertise that can facilitate wise and forward-looking decision-making. Because it is hard to assess domain-specific crystallized intelligence across many domains, it seems reasonable to use domain-general measures of crystallized intelligence as a stand-in when examining multiple domains. It is remarkable that these measures work as well as they do, and future research should disentangle the effects of domain-general versus domain-specific types of crystallized intelligence.

Crystallized intelligence could also be correlated with a related, but unmeasured construct. For example, Socioemotional Selectivity Theory (SST) posits that older adults, who perceive a limited time left in their life, try to optimize their experiences by maintaining positive emotions and by focusing their attention on positive information and stimuli (Carstensen, 2006; Carstensen, Isaacowitz, & Charles, 1999; Mather & Carstensen, 2005). For example, older adults prefer to seek positive and avoid negative stimuli (Isaacowitz, Allard, Murphy, & Schlangel,

2009) and have better memory for positive information (Charles, Mather, & Carstensen, 2003). Older adults may also adapt to declines in cognitive resources by becoming increasingly selective about how they expend their effort (Hess, 2000; Hess, Rosenberg, & Waters, 2001). Similarly, Dynamic Integration Theory (Labouvie-Vief, 2003) suggests that age-related differences in positivity bias arise because positive information is less resource demanding than negative information.

Mather (2006) argues that these differences in emotional processes may provide an explanation for why there are age differences for some types of decisions but not others. For example, positivity bias has been used to explain age-related differences in temporal discounting as well as decision-making tasks related to loss aversion (Carstensen, 2006; Carstensen, et al., 1999; Mather & Carstensen, 2005). In related research, Samanez-Larkin and colleagues (2007) found no age differences in neural activation during gain anticipation but a relative reduction in activation for older adults during loss anticipation. Although changes in positivity bias may be important for understanding decision-making across the lifespan, they present a challenge relative to more established constructs such as fluid and crystallized intelligence, as there exists no standard, domain-independent battery of measures to assess positivity bias. Again, we leave this as a topic for future research when more standardized measures are developed.

5.4 Extension to other Decision Measures

We set out to measure performance on a broad set of economically important decision-making traits and believe that would be desirable to examine an even larger set of measures. Other researchers have begun to explore the relationships between cognitive capabilities and some of these other decision variables, including risk taking (Dohmen, et al., 2010; Henninger, Madden, & Huettel, 2010), retirement savings (Banks, et al., 2010; McArdle, et al., 2009), and correctly using credit cards and other sources of borrowing (Agarwal, et al., 2010; Agarwal & Mazumder, 2010). However, most of these studies have collected only a small subset of cognitive capability measures, which limits how well they can establish the validity and

reliability of their cognitive capabilities and hence the reliability of their relationships with decision performance. Of these studies, the one with the most cognitive measures (Henninger, et al., 2010) examined the effects of processing speed and memory on risk aversion, but did not consider potential positive effects of cognitive capabilities in which older adults are better. It is impossible to study the effects of variables one does not measure, but these omitted variables may very well bias existing findings.

Two additional papers recently explored the relationships among age, cognitive capabilities, and general decision-making capabilities (DMC) as measured by the adult DMC scale (Bruine de Bruin, et al., 2011; Del Missier, et al., 2011). Bruine de Bruin and colleagues (2011) considered the effects of cognitive capabilities in which older adults are better, but did so without attempting to directly measure such capabilities. They instead used age as a proxy for any capabilities that increase with age, after partialling out the effect of fluid intelligence. However, this orthogonalization of the variables did not allow them to specifically identify a compensating role for crystallized intelligence. Del Missier and colleagues (2011) complemented these results by collecting measures for a different set of cognitive capabilities. They showed that three core executive functions affect different aspects of the DMC differently. Future research in this area would benefit from combining a broad set of cognitive capability measures, including multiple measures for fluid and crystallized intelligence, with an even broader set of decision-making traits.

Our use of multiple measures of each decision-making trait allowed us to assess reliability and increased the robustness of our results by using only the shared variance for each reliably measured task. However, further work should make use of an even larger and more diverse set of measures to assess each decision-making trait. In addition, while we attempted to include measures of anchoring and resistance to framing in our study, they proved to unreliably measure underlying individual differences. This lack of reliability may be because these tasks are too context specific or may reflect insufficient power. An example of how to potentially overcome these problems may lie in the resistance to framing component of the adult DMC scale

(Bruine de Bruin, et al., 2007, 2011), which includes 14 pairs of positively and negatively framed items including both Asian Disease style problems and attribute framing items (e.g., 20% fat or 80% lean).

Our analysis draws attention away from age *per se* as a predictor of performance and focuses instead on underlying capabilities. This distinction is important as there are many determinants of fluid and crystallized intelligence other than age, so that research that examines the effects of age by itself may not clearly identify the factors leading to differences in performance. For example, crystallized intelligence is strongly determined by education and life experiences, and therefore differences in education and life experience may appear to be differences in age, sometimes called cohort effects. If one looks only at age, one might attribute increases in performance to the wrong variable, even after controlling for years of education. Data that looks at longitudinal samples, although difficult to gather, might be very useful in further teasing these effects apart.

5.5 Cross-Sectional versus Longitudinal Studies

Although there are some clear advantages to using longitudinal studies given recent controversy over the role of cross-sectional studies of mediators of age effects (Lindenberger, von Oertzen, Ghisletta, & Hertzog, 2011; Raz & Lindenberger, 2011; Salthouse, 2011), it is worth it to briefly examine the potential tradeoffs between cross-sectional and longitudinal studies. For example, although longitudinal studies can rule out certain cohort effects and provide additional temporal information about changes, they often follow a single cohort for a shorter period of years than the 30 year range we have in our sample. This raises questions about whether their results generalize to other cohorts and whether the effects hold over longer periods. Longitudinal studies also have to carefully control for potential confounds due to retesting effects and selective attrition (Salthouse, 2010). Ideally, future work would employ cross-sectional and longitudinal data. While such work would be resource intensive, we believe that the use of web-based assessment may make it more viable.

6. CONCLUSION

Lay beliefs about age and decision performance are conflicting. One belief sees older people as wiser; another sees them as suffering from deteriorating decision skills. The compensating capabilities hypothesis suggests that there is not only truth to both beliefs, but proposes a mechanism that may help identify when each operates. In our study, we found that older people were somewhat better decision-makers than younger people, partly as a result of older people's higher levels of crystallized intelligence offsetting lower levels of fluid intelligence. Having greater experience and acquired knowledge from a lifetime of decision-making may have provided older people with another way to make good decisions.

The compensating capabilities hypothesis has important implications for matching task environments to decision-makers. For decision tasks that rely heavily on processing new information, it is likely that the negative effects of aging will outweigh its positive effects relatively early in middle-age. On the other hand, if the task relies on recognizing previously learned patterns in a stable environment, age may be an advantage and convey wisdom. Finally, the compensating capabilities hypothesis may suggest ways of modifying a decision task. To minimize the impact of declining fluid cognitive capabilities, task designers could supplement internal and scarce working memory with external memory aids to alleviate processing loads for older decision-makers. To maximize the compensatory role of crystallized intelligence, task designers could provide relevant experience with the task or analogies to similar tasks in which experience exists, akin to providing a more familiar context for the Wason selection task (Cosmides, 1989). Finally, our results make the strong prediction that increases in both fluid and crystallized intelligence produced by training may result in increases in decision performance. This possibility deserves further empirical exploration.

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Figure 1. Compensating competencies hypothesis of age differences in decision performance.

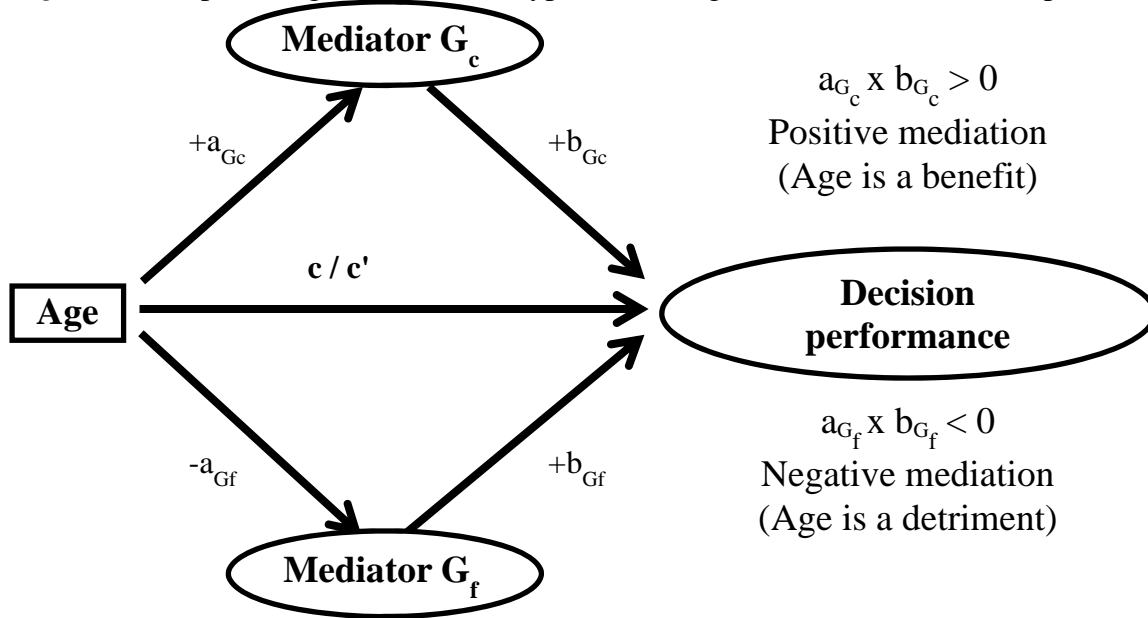


Figure 2. Cognitive competencies measurement model: Factor loadings and inter-factor correlations.

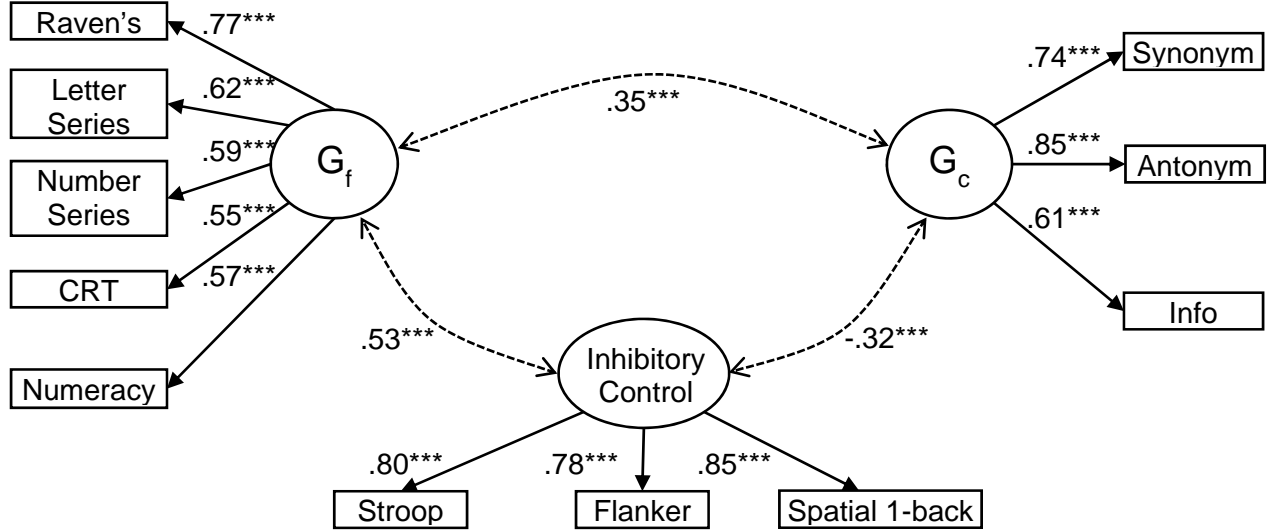
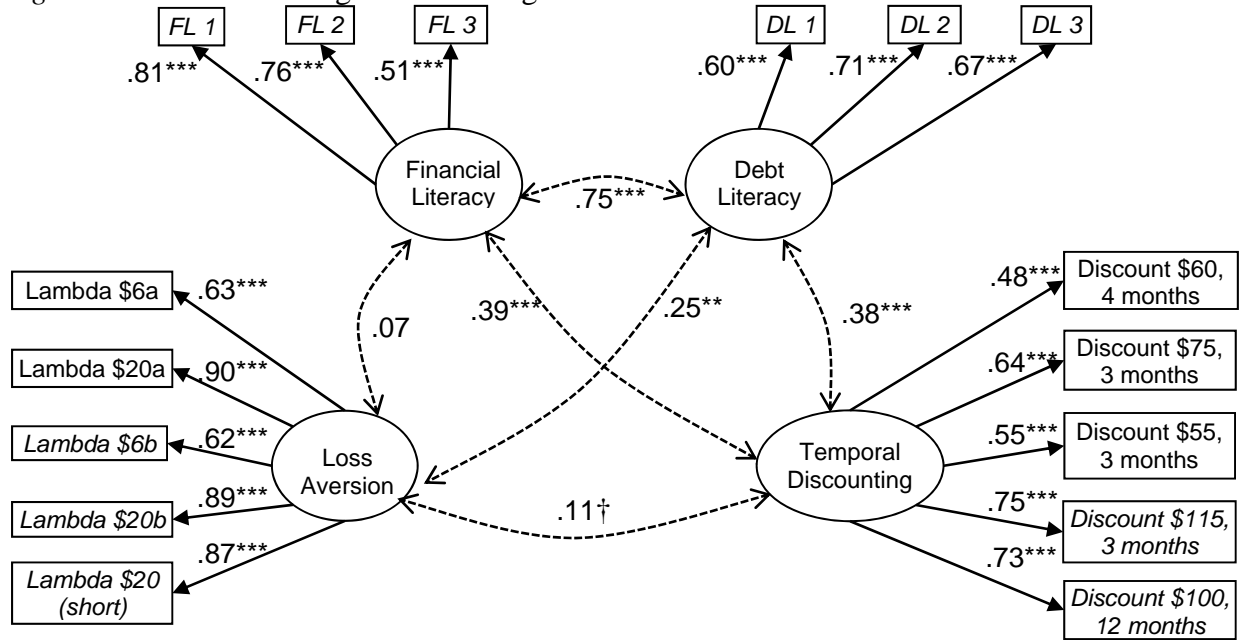
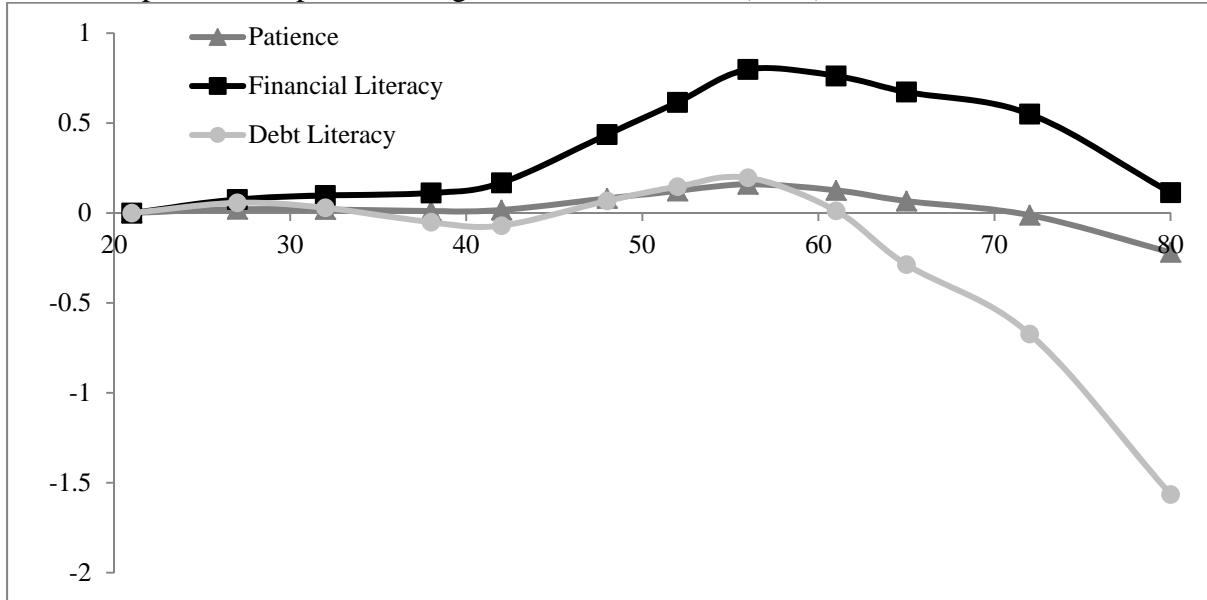


Figure 3. Decision-making factor loadings and inter-factor correlations.



Note: Tasks in italics were run in the fourth wave, one year after the first wave. *** < .001

Figure 4. Decision performance relative to 21-year-olds over the life course using our estimated relationships and extrapolated using data from Salthouse (2004).



Note: These curves do not include the effects of inhibitory control.

Table 1. Percentage of respondents in younger and older adult sample in each socioeconomic category.

		Young	Old
Gender	Percent female	67.1	64.4
Education	No degree	0.0	1.2
	High school diploma	33.5	24.5
	Associate degree, occupational	2.3	6.8
	Associate degree, academic	9.3	8.0
	Bachelor's degree	39.9	33.1
	Master's degree	12.7	17.8
	Professional degree	1.2	1.8
	Doctoral degree	1.2	6.8
Income	Less than \$19,999	20.9	6.3
	\$20,000 - \$34,999	16.9	24.4
	\$35,000 - \$49,999	17.4	23.1
	\$50,000- \$99,999	30.8	38.1
	\$100,000 - \$199,999	11.1	7.5
	Greater than \$200,000	2.9	0.6
N		173	163

Table 2. All cognitive and decision-making measures.

Category	Task	Number of Measures or Items	Wave(s)
Decision Making	Resistance to anchors	4 (2 low and 2 high)	1, 4
	Discounting	5 titrators	1, 3, 4
	Loss aversion	5 titrators	1, 3, 4
	Resistance to framing	4 items (2 pairs)	1, 4
	Financial literacy	4	4
	Debt literacy	3	4
Fluid Intelligence	Raven's Progressive Matrices	18	4
	Letter Series	15	4
	Number Series	6 (adaptive)	4
	Cognitive Reflection Test	3	1
	Numeracy	11	1
Crystallized Intelligence	Shipley's Vocabulary	40	2
	Antonym Vocabulary	10	4
	WAIS Information	28	4
Inhibitory Control	Stroop Task	2 trials, 2 minutes each	3
	Flanker Task	2 trials, 45 seconds each	3
	Spatial 1-Back	2 trials, 2 minutes each	3

Table 3. Means as a function of age group and between-measure correlations across both age groups for all cognitive measures.

Task	Means		Correlations									
	Young	Old	Raven	LS	NS	CRT	Num.	S.Voc	A.Voc	Info	Stroop	Flank
Raven's Progressive Matrices	8.15	5.17	-									
Letter Series	10.36	9.50	.48	-								
Number Series	12.0	10.1	.45	.30	-							
Cognitive Reflection Test	1.23	0.98	.42	.27	.36	-						
Numeracy	8.88	8.36	.44	.35	.36	.51	-					
Shipley's Vocabulary	22.60	30.65	.08	.17	.05	.20	.27	-				
Antonym Vocabulary	4.95	7.02	.14	.31	.13	.19	.26	.65	-			
WAIS Information	19.76	21.46	.24	.34	.27	.29	.39	.51	.52	-		
Stroop Task	1.32	2.20	.30	.13	.18	.10	.05	.30	.28	.12	-	
Flanker Task	0.74	1.18	.38	.12	.23	.11	.15	.24	.22	.06	.52	-
Spatial 1-Back	1.11	1.59	.41	.21	.32	.28	.22	.19	.21	.06	.67	.53

Note: Higher values correspond to better performance for all values except for the three inhibitory control tasks (Stroop, Flanker and Spatial 1-back). All age differences are significant at $p < .01$ or better, except for CRT and numeracy, which are significant at $p < .05$. All correlations above .11 are significant at least at $p < .05$ and above .14 at least at $p < .01$. Correlations between cognitive measures in the same competency group are shown in bold.

Table 4. Standardized factor loadings, model fits, and inter-factor correlations in the three-factor cognitive measure model and alternative models.

Task	Three-factor correlated			Three-factor uncorrelated			One-factor
	G _f	G _c	IC	G _f	G _c	IC	G
Raven's Progressive Matrices	.77***			.78***			.53***
Letter Series	.62***			.61***			.33***
Number Series	.59***			.59***			.39***
Cognitive Reflection Test	.55***			.55***			.30***
Numeracy	.57***			.57***			.27***
Shipley's Vocabulary		.74***			.75***		-.24***
Antonym Vocabulary		.85***			.84***		-.21***
WAIS Information		.61***			.60***		.01
Stroop Task			.80***			.83***	.77***
Flanker Task			.78***			.76***	.77***
Spatial 1-Back			.85***			.84***	.86***
Fit Indices							
Degrees of Freedom		40			43		43
χ^2		117.15			280.32		762.41
RMSEA		.076			.128		.204
CFI		.940			.816		.533
Inter-factor Correlations							
Fluid intelligence (G _f)	-			-			
Crystallized intelligence (G _c)	.35***	-		0	-		
Inhibitory control (IC)	.53***	-.32***	-	0	0	-	
Inter-factor Correlations (young)							
Fluid intelligence (G _f)	-			-			
Crystallized intelligence (G _c)	.65***	-		0	-		
Inhibitory control (IC)	.41***	.11*	-	0	0	-	
Inter-factor Correlations (Old)							
Fluid intelligence (G _f)	-			-			
Crystallized intelligence (G _c)	.82***	-		0	-		
Inhibitory control (IC)	.34***	.16**	-	0	0	-	
Correlation with age	-.45***	.48***	-.81***	-.46***	.49***	-.81***	-.85***
Correlation with age (young)	-.14*	.03	-.18**	-.14*	.02	-.17*	-.11
Correlation with age (old)	-.04	.20**	-.13	-.06	.20**	-.15	.09

Note. Age correlations were run in models that added paths from each factor to age. *** $p < .01$, ** $p < .05$, * $p < .10$

Table 5. Multiple-group analysis for younger and older cognitive factor invariance.

Model	d.f.	χ^2	RMSEA	CFI	$\Delta\chi^2/\Delta d.f.$
M1: No constraints	80	123.17	.057	.950	-
M2: M1 + Equal factor loadings across age groups	88	148.18	.064	.930	25.01/8, $p < .01$
M2': M1 + Equal factor loadings except for Raven's	87	136.96	.058	.942	13.79/7, $p > .05$
M3: M2' + Equal factor variances and covariances	91	140.15	.057	.943	3.19/4, $p > .52$
M4: M3 + Equal means	102	523.56	.157	.513	383.41/11, $p < .0001$

Note: χ^2 difference tests for each model in the rightmost column are relative to the model above it, except for model M2', which is compared to model M1.

Table 6. Means as a function of age group and between-measure correlations across both age groups for all decision-making performance measures.

Task	Young	Old	<i>p</i> (old≠young)	\$60, 4m	\$75, 3m	\$55, 3m	\$115, 3m	\$100, 12m
Discounting \$60, 4 months	0.43	0.48	†	-				
Discounting \$75, 3 months	0.45	0.54	**	.62***	-			
Discounting \$55, 3 months	0.44	0.46	<i>Ns</i>	.68***	.56***	-		
<i>Discounting \$115, 3 months</i>	0.54	0.56	<i>Ns</i>	.37***	.51***	.40***	-	
<i>Discounting \$100, 12 months</i>	0.70	0.72	<i>Ns</i>	.34***	.37***	.33***	.50***	-
				LA \$6a	LA \$20a	LA \$6b	LA \$20b	LA \$20c
Loss Aversion \$6a	2.56	2.56	<i>Ns</i>	-				
Loss Aversion \$20a	2.34	2.25	<i>Ns</i>	.64***	-			
<i>Loss Aversion \$6b</i>	2.69	2.46	<i>Ns</i>	.65***	.47***	-		
<i>Loss Aversion \$20b</i>	2.80	2.68	<i>Ns</i>	.53***	.41***	.82***	-	
<i>Loss Aversion \$20c</i>	2.81	2.81	<i>Ns</i>	.51***	.43***	.76***	.82***	-
				Anc H1	Anc L1	Anc H2	Anc L2	
Anchoring High 1	-0.24	0.25	***	-				
Anchoring Low 1	-0.09	0.09	<i>Ns</i>	.12*	-			
<i>Anchoring High 2</i>	-0.04	0.05	<i>Ns</i>	.15*	.00	-		
<i>Anchoring Low 2</i>	-0.09	0.09	<i>Ns</i>	.04	.11	.03	-	
				Frame 1	Frame 2			
Resistance to Framing 1	0.48	0.52	<i>Ns</i>	-				
<i>Resistance to Framing 2</i>	0.57	0.59	<i>Ns</i>	-.05	-			
				FL1	FL2	FL3	DL1	DL2
<i>Financial Literacy 1</i>	0.74	0.93	***	-				
<i>Financial Literacy 2</i>	0.55	0.86	***	.40***	-			
<i>Financial Literacy 3</i>	0.65	0.75	*	.21***	.21***	-		
<i>Debt Literacy 1</i>	0.50	0.57	<i>Ns</i>	.21***	.23***	.19**	-	
<i>Debt Literacy 2</i>	0.37	0.52	**	.28***	.25***	.16**	.33***	-
<i>Debt Literacy 3</i>	0.10	0.17	†	.01	.12*	.12*	.22***	.15**

Note: For all variables but loss aversion, higher values represent better performance. Loss aversion coefficients were left as is, so values closer to one (smaller) are better. Anchor scores were standardized and averaged across questions. Tasks in italics were run in the fourth wave, one year after the first wave. † < .10, * < .05, ** < .01, *** < .001

Table 7. Standardized factor loadings and inter-factor correlations for the decision-making tasks.

Task	Decision-making Factor			
	Temporal Discounting	Loss Aversion	Financial Literacy	Debt Literacy
Discounting \$60, 4 months	.48***			
Discounting \$75, 3 months	.64***			
Discounting \$55, 3 months	.55***			
Discounting \$115, 3 months	.75***			
Discounting \$100, 12 months	.73***			
Loss Aversion \$6a		.63***		
Loss Aversion \$20a		.90***		
Loss Aversion \$6b		.62***		
Loss Aversion \$20b		.89***		
Loss Aversion \$20c		.87***		
Financial Literacy 1			.81***	
Financial Literacy 2			.76***	
Financial Literacy 3			.51***	
Debt Literacy 1				.60***
Debt Literacy 2				.71***
Debt Literacy 3				.67***
Inter-factor Correlations				
Temporal Discounting	-			
Loss Aversion	.12†	-		
Financial Literacy	.41***	.07	-	
Debt Literacy	.39***	.25**	.75***	-
Correlation with age	.12†	.09‡	.47***	.24***

Note. Fit indices: $\chi^2(95) = 141.73$; RMSEA = .038; CFI = .948. Age correlations were run in a model that added paths from each factor to age. ‡ < .15, † < .10, * < .05, ** < .01, *** < .001

Table 8. Multiple-group analysis for younger and older decision-making factor invariance.

Model	d.f.	χ^2	RMSEA	CFI	$\Delta\chi^2/\Delta d.f.$
DM1: No constraints	196	243.88	.038	.940	-
DM2: DM1 + Equal factor loadings across age groups	206	253.37	.037	.940	11.11/10, $p > .35$
DM3: DM2 + Equal factor covariances	212	263.25	.038	.935	10.75/6, $p > .09$
DM4: DM3 + Equal factor variances	216	276.12	.041	.924	9.52/4, $p < .05$
DM4': DM3 + Equal factor variances except fin. Literacy	215	258.10	.035	.946	2.39/3, $p > .49$

Table 9. Standardized coefficients for decision-making factors as a function of cognitive factors.

Decision-making Factor	G _f	G _c	Inhibitory Control	Male	Income	Education
Temporal Discounting	.14†	.18*	-.07	.07	.12†	.16**
Loss Aversion	-.04	-.04	-.13*	.21**	.10†	.08
Financial Literacy	.32***	.63***	-.28***	.16*	.10	.35***
Debt Literacy	.58***	.51***	-.08	.37***	.02	.21**

Note. † < .10, * < .05, ** < .01, *** < .001

Table 10. Standardized coefficients for direct, indirect, and total effects of age on decision performance.

Decision-making Factor	Indirect Effect via G_f	Indirect Effect via G_c	Indirect Effect via Inhibitory Control	Total Indirect Effect	Direct Effect of Age	Total Effect of Age
Coefficient in Figure 1	$a_{Gf} \times b_{Gf}$	$a_{Gc} \times b_{Gc}$	$a_{IC} \times b_{IC}$	$\sum a_i \times b_i$	c'	c
Temporal Discounting	-.08*	.08*	-.03	-.03	.11	.08
Loss Aversion	.01	-.03	.20†	.18	-.12	.06
Financial Literacy	-.23***	.24***	-.26†	-.24	.65***	.41***
Debt Literacy	-.32***	.24***	-.26†	-.34*	.53**	.19*

Note. † < .10, * < .05, ** < .01, *** < .001

SUPPLEMENTAL MATERIAL: DESCRIPTIONS OF ALL TASKS

Decision-Making Measures

Temporal discounting was measured with five choice titrators (Green, Fry, & Myerson, 1994). These titrators used both “delay” and “accelerate” frames: The delay frame presented participants with a series of choices between a fixed smaller gift certificate today and varying amounts of a larger gift certificate at a fixed time in the future, thus allowing participants to receive more money at the cost of delayed payment. The accelerate frame instead fixed the larger, future gift certificate and varied the amount of the smaller gift certificate today, thus allowing participants to accelerate payment at the cost of receiving less money. In addition to frame, we also manipulated and counterbalanced the future time (3, 4, or 12 months) and the fixed gift certificates amount (\$50, \$75, \$100, and \$115). The dependent variable for each titrator was each participant’s exponential annual discount rate, δ , as implied by the midpoint between preferring the earlier versus later payments (i.e., the indifference point). Values of δ closer to one (larger) indicated less discounting and thus more patient preferences.

Loss aversion was also measured with five choice titrators (Fehr & Goette, 2007). Each titrator presented participants with a series of choices indicating willingness to play each of a series of binary gambles with a 50% chance of winning some fixed amount (\$6 or \$20) and a 50% chance of losing some varying amount (between \$.50 to \$7 in \$.50 increments or between \$2 to \$24 in \$2 increments). Two of the titrators in the first wave were repeated without change in the fourth wave one year later. We calculated loss aversion coefficients, λ , by dividing the gain amount by the loss amount at the indifferent point (i.e., midpoint between where the participant switches from willing to play the gamble to not willing). Values of λ were reverse coded so that larger values indicated better *loss neutrality*.

Resistance to anchors was measured with six numerical estimation questions (e.g., distance between New York and Cairo), four of which were accompanied by anchors. For each

set of three questions, participants saw one question with a high anchor (e.g., 11300 miles), one with a low anchor (e.g., 1400 miles), and one with no anchor. Questions were counterbalanced with anchor condition. We calculated standardized estimates by pooling responses across high, low, and no anchor conditions within question. Thus, the four dependent variables were the z-scores for the two low-anchor questions and reverse-coded z-scores for the two high-anchor questions. Higher values on these measures correspond to less anchoring.

Resistance to framing was measured in four different scenarios that asked participants to choose between a risky option and a sure option and varied the framing of the options as losses or gains (Tversky & Kahneman, 1981). We used the classic Asian disease problem (e.g., number of lives saved or lost), as well as variants involving potential layoffs (e.g., number of factories kept open or shut down), drought (e.g., acres of crops saved or lost) and bankruptcy (e.g., invested money saved or lost). Each participant saw either the gain version or the loss version of each scenario. Gain scenarios offered a choice between a sure but partial gain (e.g., 100% chance that 200 lives will be saved) and a risky option with chances of full gain and no gain (e.g., 33% chance that 600 lives will be saved and 67% chance that 0 lives will be saved). Loss scenarios offered a choice between a sure but partial loss (e.g., 100% chance that 400 lives will be lost) and a risky option with chances of no loss and full loss (e.g., 33% chance that 0 lives will be lost and 67% chance that 600 lives will be lost). Because these framings provide identical choices, Expected Utility maximizers should choose the same option under either framing, but Prospect Theory predicts that people susceptible to the framing will choose the sure option in the gain frame and the risky option in the loss frame. Susceptibility to framing is thus a binary measure of whether, for each pair of scenarios, choices follow consistent risk preferences regardless of framing (1 if either both risk-averse or both risk-seeking) or not (0).

Financial and debt literacy were measured using a single six-question scale composed of three financial literacy questions (Lusardi & Mitchell, 2006) designed to assess knowledge of fundamental economic concepts and three debt literacy questions (Lusardi & Tufano, 2009) designed to assess knowledge of compound interest and credit card debt (see Table S1).

Table S1. Financial and debt literacy questions.

FL1. Imagine that the interest rate on your savings account was 1% per year and inflation was 2% per year. After 1 year, would you be able to buy more than, exactly the same as, or less than today with the money in this account?

- More than today
- Exactly the same as today
- Less than today
- Do not know

FL2. Do you think that buying a single company stock usually provides a return that is more safe, equally safe, or less safe than the return on a stock mutual fund?

- More safe return than a stock mutual fund
- Equally safe return as a stock mutual fund
- Less safe return than a stock mutual fund
- Do not know

FL3. Is using money in a bank savings account to pay off credit card debt usually a good or a bad idea?

- Good idea
- Bad idea
- Do not know

DL1. Suppose you owe \$1000 on your credit card and the interest rate you are charged is 20% per year compounded annually. If you didn't pay anything off, at this interest rate, how many years would it take for the amount you owe to double?

- 2 years
- Less than 5 years
- More than 5 but less than 10 years
- More than 10 years
- Do not know

DL2. You owe \$3,000 on your credit card. You pay a minimum payment of \$30 each month. At an Annual Percentage Rate of 12% (or 1% per month), how many years would it take to eliminate your credit card debt if you made no additional new charges?

- Less than 5 years
- Between 5 and 10 years
- Between 10 and 15 years
- Never, you will continue to be in debt
- Do not know

DL3. You purchase an appliance which costs \$1,000. To pay for this appliance, you are given the following two options: a) pay 12 monthly installments of \$100 each, b) borrow at a 20% annual interest rate and pay back \$1,200 a year from now. Which is the more advantageous offer?

- Option (A)
- Option (B)
- They are the same
- Do not know

Cognitive Measures

Fluid intelligence

Our most widely recognized measure of fluid intelligence is the *Raven's Progressive Matrices* task (Raven, 1962), a non-verbal test of inductive and analytic reasoning. The version we used, adapted from Salthouse, Pink and Tucker-Drop (2008) consisted of patterns in the form of 3x3 matrices with one cell missing. Participants had to determine the underlying rules that produce the pattern of rows and columns in the matrix which of the eight choice options correctly completed the pattern. Participants had 10 minutes to answer up to 18 matrices. Each item was presented on its own page and participants could choose to skip a question by selecting “no answer” but could not return to earlier items. Performance on this task was measured by the number of correct responses (0-18) with no penalty for incorrect responses.

Letter Sets (Ekstrom, French, Harman, & Dermen, 1976; Thurstone, 1962) is another measure of inductive and reasoning ability. The version of the task used in this study was also adapted from Salthouse et al. (2008). In this task, participants were presented with five sets of letters (e.g., NOPQ, DEFL, ABCD, HIJK, and UVWX) and they had to find the rule that related four of the five sets by checking the one which did not fit that rule (e.g., DEFL). Participants had 10 minutes to complete up to 15 items. As with the Raven Progressive Matrices, each item was presented on its own page and a “no answer” option allowed participants to skip items. The score for this task was calculated by the number of correct responses with no penalty for incorrect responses.

Number Series (Thurstone, 1962) is yet another measure of inductive and reasoning ability with particular emphasis on quantitative reasoning. The version we have used in this study is a block adaptive test developed by (McArdle & Woodcock, 2009) for the HRS 2010. Each item consisted of a series of numbers (e.g., 23, 26, 30, 35, ___), and participants identified the number that correctly completed the series. All participants saw the same three items in the first block. The number of items answered correctly determined the difficulty of the three items in a second block. Thus, each participant completed six items in total, and a Rasch score was

calculated based on which second block the participant completed and how many answers they got right in each block.

The *Cognitive Reflection Test* (CRT; Frederick, 2005; Frederick, Loewenstein, & O'Donoghue, 2002) consists of three mathematical questions that yield quick, impulsive, but incorrect first responses, which need to be inhibited to arrive at the correct answer. According to Frederick, the “*three items on the CRT are ‘easy’ in the sense that their solution is easily understood when explained, yet reaching the correct answer often requires the suppression of an erroneous answer that springs ‘impulsively’ to mind*” (Frederick, 2005, p. 27). The dependent variable used is the number of correct responses (0-3) with no penalty for incorrect responses.

Numeracy (Lipkus, Samsa, & Rimer, 2001) is the ability to understand probability and mathematical concepts. The numeracy task we used in our study consists of 11 questions that test comprehension and manipulation of proportions, percentages, and probabilities. The dependent variable used is the number of correct responses (0-11) with no penalty for incorrect responses.

Crystallized intelligence

Shipley's vocabulary (Zachary, 1986) is a synonym vocabulary task that measures vocabulary knowledge. In our version, adapted from CREATE's Common Core Battery of Measures (Czaja, Charness, Dijkstra, et al., 2006; Czaja, Charness, Fisk, et al., 2006), participants choose from among four words the one most similar in meaning to a target word. Participants had 10 minutes to complete up to 40 items split into two screens of 20 items each. In this task, a visible timer counted down on the upper left hand corner of the computer screen. The dependent measure used for this task is the number of correct responses (0-40) with no penalty for incorrect responses.

Antonym vocabulary also measures vocabulary knowledge, using items developed by Salthouse (1993). In contrast to the Shipley's synonym vocabulary however, in this task participants choose from among five words the one most nearly opposite in meaning to a target word. Participants had five minutes to complete up to ten items, with a visible timer. Each item was presented on its own page but participants could choose to skip an item by selecting “no

answer”. Their score was the number of correct responses (0-10) with no penalty for incorrect responses.

The *Information* task (WAIS-III) (Wechsler, 1997) also adapted from CREATE (Czaja, Charness, Dijkstra, et al., 2006; Czaja, Charness, Fisk, et al., 2006) consisted of questions that measure general factual knowledge about events, objects, places, and people. Online administration required participants to read the questions on the computer screen and type their responses rather than having the questions read to them by a tester and answering verbally. We used the acceptable responses for each item as listed in the CREATE manual (Czaja, Charness, Dijkstra, et al., 2006) to determine whether an answer is correct. Because we could not prompt participants to give further details for a question, we could only code answers as correct (1) or incorrect (0) (instead of the original 0, 1, 2 scoring). Participants answered 28 questions without time restriction. The dependent measure used for this task is the number of correct responses (0-28) with no penalty for incorrect responses.

Inhibitory Control

The *Spatial 1-back* (Spatial Speed Match¹) task belongs to a family of N-back tasks that measure the capacity to update and actively manipulate working memory contents. The version of the task we employed in our study tests visuo-spatial information processing. Participants were presented with three circles, two white and one blue, which formed a triangle on the screen. In each trial, they saw the same triangle but the blue circle could appear in one of the other corners of the triangle. Therefore, participants had to evaluate if the location of the blue circle was had changed from the trial before (1-back). As the accuracy level on this task was very high for young and old people, the dependent measure we used is participants’ average reaction time.

The *Stroop* (Color Match) task measures cognitive flexibility and response inhibition capacity (Stroop, 1935). In the version used in this study, each trial displayed two words on the screen. The word on the left appeared in black font and indicated the name of a color (i.e., blue,

¹ All inhibitory control tasks were adapted from tasks developed by Lumos Labs (Lumosity.com). The name of each task in parentheses is the name for the task on the Lumosity website.

green, red, etc.). The word on the right was also the name of a color and appeared in either the same color font as the semantic value of the color word on the left of the screen (e.g., congruent trials) or in a different color font (e.g., incongruent trials). Participants judged as quickly as possible if the semantic value of the word on the left corresponded to the font color of the word on the right. Participants had two minutes to finish as many trials as possible. The dependent measure was the difference in reaction times between incongruent and congruent trials, coded such that higher values correspond to better inhibition capacity.

The *Flanker* (Lost in Migration) task measures focus and resistance to interference. In this task, participants see a central item in a certain orientation flanked by distracting items in either the same or different orientations. In the version used in this study, participants saw five birds flying in a “V” shape. The task was to report the direction the middle bird (target) was flying by pressing one of the four arrow keys. In congruent trials, the other four birds were all flying in the same direction as the target and, in incongruent trials, they were all flying in a different direction. Participants had 45 seconds to finish as many trials as possible. The dependent measure was the difference in reaction times between incongruent and congruent trials, coded such that higher values correspond to better inhibition capacity.

Table S1. Means as a function of age group, and standard deviations and correlations across both age groups for all measures.

Measures	Means		SD	p(Old<# young)	Correlations																																					
	Young	Old			Raven	Letter Series	Number Series	CRT	Numeracy	Shibley	Antonym	Info	Stroop	Flanker	Spatial 1-back	D \$60, 3m	D \$75, 3m	D \$55, 3m	D \$115, 3m	D \$100, 12m	LA \$6a	LA \$20a	LA \$6b	LA \$20b	LA \$20c	Anc H1	Anc L1	Anc H2	Anc L2	Frame 1	Frame 2	FL1	FL2	FL3	DL1	DL2						
Raven's Matrices	8.15	5.17	3.55	p<.001	-																																					
Letter Series	10.36	9.50	2.72	p<.001	0.49***	-																																				
Number Series	12.00	10.10	3.38	p<.001	0.45***	0.23***	-																																			
Cognitive Reflection Test	1.23	0.98	1.05	p<.01	0.42***	0.31***	0.43***	-																																		
Numeracy	8.88	8.36	2.11	p<.01	0.43	0.32*	0.38	0.53***	-																																	
Shibley's Vocabulary	22.60	30.65	8.92	p<.001	0.07*	0.11***	0.01**	0.21***	0.22***	-																																
Antonym Vocabulary	4.95	7.02	2.98	p<.001	0.14***	0.28***	0.15***	0.19***	0.23***	0.63***	-																															
WAIS Information	19.76	21.46	4.17	p<.001	0.23***	0.30**	0.22***	0.30†	0.34	0.46***	0.51***	-																														
Stroop Task	1.32	2.20	0.71	p<.001	0.33***	0.15***	0.21***	0.10*	0.05**	-0.30***	-0.28***	-0.10	-																													
Flanker Task	0.74	1.18	0.39	p<.001	0.41***	0.20***	0.21***	0.12***	0.18***	-0.31**	-0.24***	-0.05	0.64***	-																												
Spatial 1-Back	1.11	1.59	0.39	p<.001	0.42	0.25	0.30	0.29	0.24	-0.17	-0.21**	-0.02†	0.70†	0.63	-																											
Discounting \$60, 4 months	0.43	0.48	0.29	p<.10	-0.02	0.05	0.00	0.01	0.07	0.05*	0.17***	0.10*	-0.10*	-0.06*	-0.05	-																										
Discounting \$75, 3 months	0.45	0.54	0.28	p<.01	-0.03	0.08	0.05	0.07	0.08	0.11	0.20†	0.12	-0.13	-0.14	-0.05	0.62***	-																									
Discounting \$55, 3 months	0.44	0.46	0.25	ns	-0.03	0.05*	-0.01*	-0.01***	-0.02***	0.03†	0.10**	0.03***	-0.07	0.01	-0.03	0.68***	0.56***	-																								
Discounting \$115, 3 months	0.54	0.56	0.26	ns	0.09	0.12	0.12	0.19**	0.19*	0.10	0.18	0.22**	0.01	-0.05	0.09	0.37***	0.51***	0.40***	-																							
Discounting \$100, 12 months	0.70	0.72	0.15	ns	0.04	0.06	0.09*	0.18	0.13†	0.01	0.07	0.19*	-0.08	-0.10	0.04	0.34	0.37	0.33	0.50	-																						
Loss Aversion \$6a	2.56	2.56	2.33	ns	-0.01	0.04	0.13	0.06	0.10	0.06	-0.05	0.12	-0.06	-0.03	-0.04	0.03	0.00	0.05*	0.04	0.15**	-																					
Loss Aversion \$20a	2.34	2.25	1.41	ns	-0.04	-0.04	0.04	0.05	0.05	-0.01	-0.05	0.06	-0.08**	-0.02	-0.02*	0.07	0.05	0.11	0.07	0.16**	0.77***	-																				
Loss Aversion \$6b	2.69	2.46	2.12	ns	-0.08	-0.06	0.09	0.02	0.01	0.00	-0.01	0.05	-0.15*	-0.07	-0.14†	0.00	0.01	0.04	0.00	0.16†	0.59***	0.53***	-																			
Loss Aversion \$20b	2.80	2.68	2.14	ns	-0.06	-0.08	0.08	0.00	-0.01	0.01	-0.03	0.03	-0.14	-0.06	-0.10	0.03	0.06	0.06	0.00	0.11**	0.53***	0.50***	0.83***	-																		
Loss Aversion \$20c	2.81	2.81	2.19	ns	-0.03*	-0.08	0.09	0.07	0.02	-0.01**	-0.08*	0.06	-0.09*	-0.03**	-0.04	0.07	0.05	0.06	0.03	0.20	0.52	0.52	0.76†	0.83	-																	
Anchoring High 1	-0.24	0.25	1.00	p<.001	-0.12	-0.06	0.04	0.05*	0.04	0.15	0.12	0.06*	-0.15	-0.18	-0.09	0.07	0.08	0.05	0.02	0.09†	0.06	-0.03	-0.10	-0.02	0.00	-																
Anchoring Low 1	-0.09	0.09	1.00	ns	-0.02	0.00	0.07	0.13	0.05	0.06	-0.03	0.14	0.00	-0.09	-0.08	0.02	0.08	0.03	-0.01	0.10	0.07	0.05	0.01	0.02	0.02	0.12*	-															
Anchoring High 2	-0.04	0.05	1.00	ns	-0.03	-0.05	-0.07	0.01	0.00	0.03	0.08	0.08	-0.08	0.01	-0.05	-0.04	-0.07	0.02	0.00	-0.02	-0.05†	-0.02	-0.07	-0.09†	-0.03	0.15	-0.03	-														
Anchoring Low 2	-0.09	0.09	1.00	ns	-0.01	-0.04	-0.09	-0.11	-0.04	0.07	0.05	0.06*	-0.07	0.03	-0.11	-0.02	0.04	0.07	-0.01	-0.07	-0.13	-0.05	-0.09	-0.12	-0.11	0.04	0.11	0.03†	-													
Resistance to Framing 1	0.48	0.52	0.50	ns	0.08	0.08	0.02	0.00	0.07	0.05	0.07	0.12	-0.01	-0.01	0.00	0.02	0.01	0.02	0.01	0.02	0.00	-0.05	-0.05	-0.05	-0.09	-0.03†	-0.03	-0.11	0.13†	-												
Resistance to Framing 2	0.57	0.59	0.49	ns	-0.02	-0.01**	-0.04*	0.00***	0.02***	0.04***	-0.07***	-0.03***	-0.02**	-0.01*	-0.02	0.06*	0.01*	0.08	0.03***	0.05**	0.02	0.07	-0.02	-0.05	-0.01	-0.11	-0.03	-0.06*	-0.12	-0.05	-											
Financial Literacy 1	0.74	0.93	0.38	p<.001	0.06	0.15**	0.11	0.19***	0.21***	0.30***	0.32***	0.25***	-0.15***	-0.13***	-0.03**	0.12	0.13**	0.07	0.19***	0.16**	-0.03	0.02	0.03	0.00	0.01	0.06*	0.05	0.15	-0.04	-0.01	-0.09	-										
Financial Literacy 2	0.55	0.86	0.46	p<.001	0.02†	0.15	0.00*	0.18***	0.19**	0.29*	0.30**	0.32***	-0.22	-0.20	-0.17	0.08	0.15*	0.07	0.22*	0.19**	-0.05	0.08	-0.01	0.02	0.01	0.12	0.08*	0.06	0.02	0.06	-0.06†	0.40***	-									
Financial Literacy 3	0.65	0.75	0.49	p<.05	0.11***	0.02***	0.13***	0.18***	0.17***	0.14***	0.16***	0.24***	-0.01	-0.02	-0.03*	0.06	0.12	0.03	0.13**	0.17*	0.03	0.03†	0.05	0.05	0.07	0.06	0.11	-0.02	-0.03	0.05	-0.09	0.21***	0.21***	-								
Debt Literacy 1	0.50	0.57	0.46	ns	0.24*	0.23**	0.25***	0.39***	0.30***	0.25***	0.24***	0.26***	-0.03*	0.03	0.12	0.07*	0.09*	0.04*	0.18**	0.12**	0.07	0.11	0.03†	-0.01†	-0.01	0.07†	0.04	-0.07	-0.09	0.07	0.04	0.21***	0.23***	0.19**	-							
Debt Literacy 2	0.37	0.52	0.50	p<.01	0.11	0.18	0.21	0.30***	0.28***	0.20	0.24**	0.27**	-0.11*	-0.05	-0.02	0.12*	0.12*	0.13**	0.18	0.16**	0.05***	0.07**	0.10**	0.09***	0.09**	0.10*	0.09	0.01	-0.05	0.00	0.06	0.28	0.25*	0.16*	0.33***	-						
Debt Literacy 3	0.10	0.17	0.50	p<.10	0.08	0.04	0.07	0.21***	0.22***	0.05	0.15*	0.16***	-0.13*	0.02	-0.08	0.12*	0.11*	0.17***	0.07	0.19***	0.20***	0.17***	0.17***	0.19***	0.18***	0.13*	0.04	0.06	0.00	0.02	-0.01	0.01	0.12*	0.12*	0.22***	0.15*	-					

Note: Higher values correspond to better performance for all values except for loss version (smaller values, closer to one are better) and the three inhibitory control tasks (Stroop, Flanker and Spatial 1-back). Anchor scores were standardized and averaged across questions. Correlations between cognitive measures in the same competency group are shown in bold.

† < .10, * < .05, ** < .01, *** < .001