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# Processing Speed and Memory Mediate Age-Related Differences in Decision Making

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Decision making under risk changes with age. Increases in risk aversion with age have been most commonly characterized, although older adults may be risk seeking in some decision contexts. An important, and unanswered, question is whether these changes in decision making reflect a direct effect of aging or, alternatively, an indirect effect caused by age-related changes in specific cognitive processes. In the current study, older adults ($M = 71$ years) and younger adults ($M = 24$ years) completed a battery of tests of cognitive capacities and decision-making preferences. The results indicated systematic effects of age upon decision quality—with both increased risk seeking and increased risk aversion observed in different tasks—consistent with prior studies. Path analyses, however, revealed that age-related effects were mediated by individual differences in processing speed and memory. When those variables were included in the model, age was no longer a significant predictor of decision quality. The authors conclude that the reduction in decision quality and associated changes in risk preferences commonly ascribed to aging are instead mediated by age-related changes in underlying cognitive capacities.

*Keywords:* risk, decision making, aging, cognition, path analysis



Older adults face many decisions involving risk. Some of these decisions involve health outcomes, as when balancing potential quality of life against the promise of an unproven cancer treatment. Others involve complex economic trade-offs, often exacerbated by increasing life span and delayed retirement. Where studied, usually in financial measures, older adults' real-world decisions involving risk are often of objectively worse quality than those of younger adults, both in laboratory and real-world settings, with an abrupt decrease in decision-making skill observed in individuals over 70 years of age (Korniotis & Kumar, in press). As examples, older adults within that age range earn 3%–5% lower risk-adjusted annual returns (Korniotis & Kumar, in press) and obtain systematically worse outcomes on a wide variety of financial instruments (Agarwal, Driscoll, Gabaix, & Laibson, 2007), even when controlling for confounding factors like income, investment horizon, and desired rate of return. Compared to younger investors, older investors devote proportionally less of their savings to equities (Kumar, 2007) or other risky assets (Bellante & Green, 2004). In short, substantial evidence demonstrates that older adults are more likely to make poor-quality financial decisions, often leading to significant negative personal consequences.

A widely held interpretation of these and other real-world phenomena is that normal aging leads to an increase in risk aversion. As typically defined within economic contexts, "risk" refers to variability in the potential outcomes of a decision, often formalized by mathematical functions like the coefficient of variation (Weber, Blais, & Betz, 2002). (Note that "high risk" decisions involve more variable, not necessarily more negative, outcomes. Taking on increased risk can be adaptive in many situations.) Accordingly, one's "risk preferences" reflect tendencies toward or against taking on risk when making decisions, such that a risk-averse individual would be willing to sacrifice overall value to avoid selecting a risky option. Many studies support the idea that that risk aversion increases across the life span. Older adults are more likely to avoid options with increased risk and to allow others to make risky decisions, particularly when faced with decisions that involve major life events (Deber, Kraetschmer, & Irvine, 1996; Mather, 2006; Okun, 1976; Wallach & Kogan, 1961). Moreover, a decreased tolerance for risk may shape real-world financial decision behavior (Bakshi & Chen, 1994; Blume & Friend, 1975; Jianakoplos & Bernasek, 1998; Riley & Chow, 1992), which may include salutary consequences like increased diversification (Goetzmann & Kumar, 2008).

Yet, more recent studies point to a different conclusion: The context in which a decision is made influences whether older adults seek or avoid risk. In some settings, older and younger adults exhibit similar levels of risk aversion (Dror, Katona, & Mungur, 1998; Kovalchik, Camerer, Grether, Plott, & Allman, 2005; MacPherson, Phillips, & Della Sala, 2002), with differences

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between age-groups perhaps reflecting differences in information processing strategies rather than general attitudes toward risk (Wood, Busemeyer, Koling, Cox, & Davis, 2005). Older adults sometimes evince less risk aversion than younger adults. When faced with decisions involving probabilistic outcomes, older adults are less likely to choose low-risk options (Deakin, Aitken, Robbins, & Sahakian, 2004) and show poorer adjustment of their wagers in a laboratory gambling paradigm to the true probability level (Deakin et al., 2004; Rahman, Sahakian, Hodges, Rogers, & Robbins, 1999). Other work points to dramatic variability among older adults, such that task context predicts whether some older adults are more risk seeking than younger adults (Denburg, Tranel, & Bechara, 2005). Collectively, these studies argue for a more nuanced perspective on the effects of age on decision making: The risk aversion generally attributable to older adults may be better characterized as a consequence of specific, complex task demands, rather than a systematic difference in risk preference (MacPherson et al., 2002; Mather, 2006; Peters, Finucane, MacGregor, & Slovic, 2000; Yates & Patalano, 1999; Zwahr, Park, & Shifren, 1999). From this perspective, the cognitive changes associated with normal aging lead not to generalized risk aversion but to a reduction in *decision quality*, or the ability to adaptively obtain and process relevant information to optimize decision making.

Here, we adopt the hypothesis that the differences between younger and older adults in decision quality—which may be manifest in different risk preferences, depending on the task—result from indirect effects of age upon underlying cognitive capacities (Kramer & Madden, 2008; Park et al., 1996; Raz, 2000; Salthouse, 1985, 1993, 1996; Singer, Verhaeghan, Ghisletta, Lindenberger, & Baltes, 2003). In particular, the abilities to manipulate (i.e., processing speed) and retain (i.e., memory) acquired information exhibit steady decline over the life span, with a marked decline after about 60–70 years of age (Lindenberger, Mayr, & Kliegl, 1993; Madden, 2001; Park et al., 1996). An influential approach for understanding these age-related changes in behavior, as advocated by Salthouse, postulates that even small changes in these core capacities can lead to large changes in more complex behaviors (Salthouse, 2001). For example, age-related declines in fluid intelligence and memory can account for the reduced performance of older adults on a range of tasks including reasoning, spatial visualization, and associative memory (Salthouse, 2001). Considered similarly, age-related changes in decision quality could reflect indirect effects attributable to decline in core processing capacities, rather than a direct effect of age upon decision making.

To test this hypothesis, we evaluated older and younger adults using a battery of cognitive and decision-making tasks. We selected cognitive tasks on the basis of the prior literature to measure aspects of processing speed and memory, domains on which there exists clear evidence of age-related decline. We selected three decision-making tasks that evaluated potentially distinct aspects of decision making: The Iowa Gambling Task (IGT) requires integrating the past history of monetary gains and losses (Bechara, Damasio, Damasio, & Anderson, 1994); the Cambridge Gambling Task (CGT) involves allocating financial stakes according to relative probabilities (Rogers et al., 1999); and the Balloon Analogue Risk Task (BART) involves risking current earnings for potentially larger rewards (Lejuez et al., 2002). We had two key predictions: First, we predicted that older adults would exhibit reduced decision quality in these tasks. We note that, depending on the requirements of the task, this might be manifest as either more risk-seeking or more risk-averse behavior. Second, we expected that the effects of age-group on decision making would be mediated by individual differences in processing speed and memory, as shown through path analyses.

# Method

## Participants and Procedures

We tested two groups of participants: 54 older adults between 66 and 76 years of age ($M$ = 70.7 years, $SD$ = 3.0; 50% female) and 58 younger adults between 18 and 35 years of age ($M$ = 23.4 years, $SD$ = 4.4; 47% female). Participants had no prior history of stroke, neurological or psychiatric disorder, head injury, or dementia. Years of education were comparable for the older adults ($M$ = 15.9 years, $SD$ = 2.7) and younger adults ($M$ =15.0 years, $SD$ = 1.9). Participants were compensated a minimum of $20, with the opportunity to earn up to an additional $15 based on performance during the decision-making tasks. Participants provided written informed consent under a protocol approved by the Duke University Medical Center Institutional Review Board.

## Materials

Participants completed a battery of decision-making and psychometric tests within a single session lasting approximately two hours. For each decision-making test, participants received a known bonus payment if their performance exceeded a fixed threshold. Participants were not told those thresholds; instead, to ensure their continual adherence to task instructions, we instructed them to maximize their scores to increase their chances of receiving the bonus payment.

We administered three computerized decision-making tasks, each chosen to assess a distinct component of decision quality. For two of the tasks (IGT and CGT), higher quality decisions were associated with lower risk (i.e., reduced variance in potential outcomes), whereas for the final task (BART), higher quality decisions were associated with higher risk.

During the IGT, participants selected cards from four decks, each with different distributions of monetary gains and losses. Two of the decks have high gains (+$100/trial) but also infrequent high losses, and thus they have negative expected value. The other two decks have low gains (+$50/trial) but also relatively low losses, and thus they have positive expected value. Adaptive performance in this task required remembering the obtained payoffs (particularly, the nature of the infrequent losses) to identify those decks with positive expected value over time (Bechara et al., 1994). Our dependent measure was the proportion of cards chosen from the two lower-risk decks over the last 50 trials (out of 100 in total). Higher values indicate higher quality but lower risk decision making. Participants received a bonus of $5 if they ended the game with at least their starting endowment.

On each trial of the CGT, participants viewed an array of 10 boxes—each colored blue or red, with color ratios from 9:1 to 5:5—one of which concealed a hidden token (Rogers et al., 1999). Participants bet on the token location by selecting one color and indicating the points to be wagered. Note that the possible point wagers were shown in either increasing order or decreasing order, counterbalanced across trials; this design minimizes the contribution of impulsivity to choice. Optimal decision making in this task involved consistently selecting the higher probability option and wagering more points when the color ratios were more uneven. Decision quality was defined using an index proportional to the number of boxes for the chosen color (i.e., choosing the color with more boxes yielded a lower score). Higher values indicate higher quality but lower risk decision making. Participants received a bonus of $5 if they found the token on more than half of all trials.

Finally, during the BART, participants viewed a series of 10 virtual balloons and could earn additional money by pumping up each balloon in turn (Lejuez et al., 2002). Each keypress increased the size of the active balloon and earned one cent, at a small risk of popping the balloon and losing the money accumulated for that balloon. Decision quality was defined as the average number of pumps on the unpopped balloons (i.e., trials on which the participant chose to stop pressing and bank the accumulated money). Note that optimal behavior on this task, based on the payoff structure and probability of popping set by the computerized task, was to pump exactly 64 times (Lejuez et al., 2002). Our participants, similar to those in prior reports, tended to pump too few times. Thus, higher values on our measure indicate both higher quality and higher risk decisions. Participants received a monetary bonus of the total amount collected across all balloons.

We also administered eight psychometric tasks chosen to assess cognitive abilities. In an immediate memory task, patterned after the California Verbal Learning Test (Delis, Kramer, Kaplan, & Ober, 2000), participants read a list of 16 sequentially presented words aloud and thereafter recalled as many as possible. Then, following a 20-min delay, participants again recalled as many words as possible from the same list, providing a measure of delayed memory. Thereafter, participants viewed a list of 32 words, 16 from the immediate memory task and 16 new, and the participants identified each word as “old” or “new” in a test of recognition memory. The Digit Span task was adapted from the Wechsler Adult Intelligence scales (Wechsler, 1981). Participants listened to a series of numbers and then recited as many as possible in backward order. For the previous tests, we used the number of correct responses (or proportion, for the recognition test) as the dependent measure. In the simple reaction time task, participants pressed a button as quickly as possible to the occurrence of a target shape at the center of the screen. The choice reaction time task used a similar procedure but involved two possible stimuli and responses: press a key on the left when a left-pointing arrow appeared, or press a key on the right when a right-pointing arrow appeared. In the Digit Symbol task, similar to that in the Wechsler Adult Intelligence Scale (Wechsler, 1981), participants viewed a series of number–symbol pairings and judged whether each pairing matched a master key of number–symbol associations, which remained on the screen throughout the task. Finally, we used an adaptation of the Stroop task (MacLeod, 1991) that required participants to identify the font color of colored words. On some trials the font color was congruent with the color name (e.g., the word *red* displayed in a red font), whereas on other trials the font color and color name were incongruent (e.g., the word *red* displayed in a blue font). For these final four tasks, we used median latency of correct responses as the outcome measure.

## Statistical Analyses

We adopted a hierarchical approach to data analysis. We initially evaluated whether there was an effect of age-group (coded as a categorical variable) on the decision-making and cognitive tasks. Next, we reduced the data from the cognitive tasks using factor analysis, based on all participants. In this factor analysis, the dependent variables were standardized measures ($z$ scores), defined relative to the mean and standard deviation of the younger adults’ data. In preliminary analyses, we evaluated each age-group separately to determine similarities in factor loadings between the older and younger adults. The factor loadings were very similar, so we combined the two groups to increase the sample size. We then subjected the full data set (112 participants by 8 $z$ scores) to a factor analysis with varimax rotation, using scree plots to identify meaningful factors. For all reported analyses, we used a loading threshold of 0.60. To ensure that the choice of this threshold did not bias the results, we repeated all analyses using thresholds of 0.30 and 0.45. Using either of these thresholds did not appreciably change overall model fit or the significance of individual model pathways.

We next used path analyses to evaluate the critical test of our hypothesis: Do differences in decision quality reflect direct effects of aging, or do they reflect indirect effects of age differences in specific cognitive processes? Using the software program Amos (Arbuckle, 2006), we created an initial model that included direct paths from age to the three decision-making scores (3 paths), as well as indirect paths that treated the cognitive factors as mediating variables (8 paths). We used three indices to evaluate the fit of the model: the root mean square error of approximation (RMSEA), the comparative fit index (CFI), and the goodness-of-fit index (GFI). The RMSEA corrects for model complexity, favors a simpler model, and does not assume a perfect fit or central chi-square distribution. Ideal RMSEA values approach zero. The CFI indicates the improvement of the hypothesized model compared to the saturated model in a noncentralized population, whereas the GFI indicates the proportion of variance explained by the model. For both, ideal values approach 1.0, with values of 0.90 and above indicating good fit (Kline, 2005).

# Results

All participants completed the full set of experimental tasks, and thus all results include data from 112 participants.

## Age-Related Changes in Decision Quality

Consistent with our first hypothesis, differences in decision quality were exhibited by older and younger adults on two of our three decision tasks (see Table 1). Older adults were more likely to choose options that had a low probability of winning on the CGT ($p < .001$). This choice pattern means that the older adults both made significantly lower quality decisions than younger adults and took on proportionally more risk, compared to the expected value of potential outcomes. The decisions of older adults were also of significantly lower quality than those of younger adults on the BART ($p < .001$); however, for this task, both groups made risk-averse decisions (e.g., too few pumps), with the older adults being more risk averse than the younger adults. No significant

Table 1
*Age Differences on Decision-Making Tasks*

| Task | Younger adults *M* | Younger adults *SD* | Older adults *M* | Older adults *SD* |
|---|---|---|---|---|
| IGT | $-6.8_a$ | 16.7 | $-3.6_a$ | 20.2 |
| CGT | $-2.0_a$ | 0.5 | $-1.4_b$ | 0.8 |
| BART | $40.8_a$ | 13.1 | $31.0_b$ | 14.3 |

*Note.* Age range = 18–35 years for younger adults ($n$ = 58) and 66–76 years for older adults ($n$ = 54). Higher scores indicate number of choices of more disadvantageous decks (i.e., high gain with high loss) on the Iowa Gambling Task (IGT), number of choices of lower probability odds (e.g., choice of blue box when there is 1 blue and 9 red) on the Cambridge Gambling Task (CGT), and average number of choices of more monetary gains in the face of increasing risk of loss (i.e., more pumps of a balloon) on the Balloon Analogue Risk Task (BART). Means in the same row that do not share subscripts are different by $t$ test at $p < .01$.

group differences were observed in decision tendencies in the IGT (i.e., the age-groups were equally likely to select the low-expected-value decks).

## Age-Related Changes in Cognitive Abilities

Factor analysis yielded two significant factors (see Table 2). The first, which we hereafter label processing speed, comprised the simple reaction time, choice reaction time, and Digit Symbol tests, all loading positively. The second factor, which we hereafter label memory, comprised the immediate memory and delayed memory tests, both loading positively. The Digit Span, Stroop, and recognition memory tasks did not load on either factor at the threshold level, and thus they were excluded from further analyses. Older adults exhibited lower mean performance than younger adults on both the processing speed and memory factors (see Table 3; both $p$s $< .001$), and this result also held for every individual measure included in the two factors ($p$s $< .001$).

Correlation values between the cognitive factors and the decision tasks are presented in Table 4. As expected, the two cognitive factors have a moderate positive correlation ($r$ = .41, $p < .01$), consistent with an overarching construct of cognitive functioning. Of the decision tasks, the CGT and BART have a moderate positive correlation ($r$ = .33, $p < .01$), indicating that these two tasks reflect, in part, some shared aspects of decision making. Processing speed was significantly positively correlated with the CGT ($r$ = .51, $p < .01$) and was positively correlated with the BART ($r$ = .29, $p < .01$), indicating the involvement of processing speed with these two decision-making tasks. Memory was significantly positively correlated with the CGT ($r$ = .35, $p < .01$), indicating the involvement of a memory component in performance on the CGT.

Table 2
*Factor Loadings for the Cognitive Measures*

| Measure | Factor 1 | Factor 2 |
|---|---|---|
| Immediate memory | −0.19 | **0.81** |
| Delayed memory | −0.22 | **0.83** |
| Recognition memory | 0.47 | −0.43 |
| Digit Span | −0.31 | 0.28 |
| Stroop | 0.26 | −0.04 |
| Digit Symbol | **0.62** | −0.46 |
| Choice reaction time | **0.84** | −0.26 |
| Simple reaction time | **0.69** | −0.11 |

*Note.* Factor loadings >0.60 are presented in bold font.

Table 3
*Age Differences on Cognitive Tasks and Cognitive Domains*

| Measure | Younger adults *M* | Younger adults *SD* | Older adults *M* | Older adults *SD* |
|---|---|---|---|---|
| Immediate memory | $10.4_a$ | 2.2 | $9.0_b$ | 2.2 |
| Delayed memory | $9.2_a$ | 2.6 | $6.7_b$ | 2.6 |
| Recognition memory | $0.8_a$ | 0.1 | $0.7_b$ | 0.2 |
| Digit Span | $8.0_a$ | 2.7 | $7.6_a$ | 2.4 |
| Stroop | $52_a$ | 71 | $94_b$ | 119 |
| Digit Symbol | $1{,}373_a$ | 255 | $1{,}883_b$ | 344 |
| Choice reaction time | $319_a$ | 42 | $386_b$ | 58 |
| Simple reaction time | $289_a$ | 31 | $316_b$ | 43 |
| Processing speed | 0.0 | 0.8 | −1.3 | 1.0 |
| Memory | 0.0 | 1.0 | −0.8 | 1.0 |

*Note.* Age range = 18–35 years for younger adults ($n$ = 58) and 66–76 years for older adults ($n$ = 54). Means in the same row that do not share subscripts are different by $t$ test at $p < .05$. Factor values for processing speed and memory are normalized to the mean of the younger adult sample.

## Influence of Cognitive Abilities on Decision Making

To test whether age differences in decision making reflect direct effects of aging or indirect effects of changes in cognitive processes, we conducted a series of path analyses. Our initial model (see Figure 1) included paths that linked age to processing speed and memory, which in turn each linked to IGT, CGT, and BART scores. We also included direct paths between age and each of the risk scores (IGT, CGT, and BART). Although this initial model provided a good fit to the data, $\chi^2(3) = 5.167$, $p = .160$, RMSEA = 0.081, CFI = 0.985, GFI = 0.985, the RMSEA value was only adequate and there was evidence that two pairs of variables shared a common residual error. In particular, there was a significant association between the error terms associated with processing speed and memory ($r$ = .20, $p < .05$) and the error terms associated with the CGT and the BART ($r = -.21$, $p < .05$). These values indicated that some overlapping residual error of these variables changed jointly across the participants.

Table 4
*Correlations Between Cognitive Factors and Decision Tasks*

| Variable | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. Processing | — | | | | |
| 2. Memory | .41** | — | | | |
| 3. IGT | −.11 | .12 | — | | |
| 4. CGT | .51** | .35** | −.06 | — | |
| 5. BART | .29** | .18 | −.12 | .33** | — |

*Note.* IGT = Iowa Gambling Task; CGT = Cambridge Gambling Task; BART = Balloon Analogue Risk Task.
** $p < .01$.

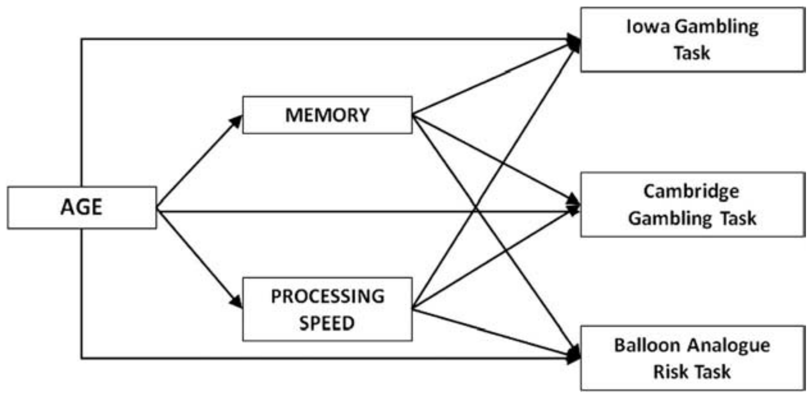


*Figure 1.* Hypothesized model for the predictive relationships among age, cognitive domains, and decision-making tasks.

We therefore revised the initial model to include paths between the error terms associated with processing speed and memory and between the CGT and BART scores. The final model (see Figure 2) was an excellent fit to the experimental data: $\chi^2(2) = 0.133$, $p = .936$, RMSEA $< 0.001$, CFI $= 1.000$, GFI $= 1.000$. Path coefficients and significance levels are provided in Table 5. Most critically, age makes no significant contribution to our decision-making measures when the cognitive variables are included as mediators.

We next used a bootstrapping approach to confirm the robustness of this model. We estimated, across 2,000 replications, our model parameters by drawing new participant samples (with replacement) and estimating model fit. As shown in Table 6, the bootstrapped 95% confidence interval excluded a null effect (i.e., a regression coefficient of 0) for all model paths with significant weighting in our model, with the one exception of the path between memory and the IGT. Because this last path did not survive the bootstrapping significance test, we do not consider it further in our discussion. We conclude that the fit of the overall model and the significance of the remaining path coefficients are likely to generalize beyond our specific participant sample.

Together, these results provide strong evidence for our second hypothesis: The effects of age upon decision making reflect an indirect influence of age-related cognitive decline (see Figure 2 and Table 5). Examination of specific model paths revealed that increases in processing speed predicted higher quality choices on the CGT ($p < .01$) and BART ($p < .05$), with the former manifest as a decrease in risk-seeking choices and the latter manifest as an increase in risk-seeking choices. Better memory performance predicted an increase in decision quality on the IGT ($p < .05$), reflecting a decrease in selection of the high-risk decks.

As a post hoc test, these analyses were repeated within the older adult sample. The overall model fit was reduced: $\chi^2(2) = 1.12$, $p = 0.571$, RMSEA $= 0.067$, CFI $= 0.96$, GFI $= 0.993$. Examination of individual paths revealed that age was a significant predictor of processing speed ($p < .01$) but not of memory ($p > .10$) and that higher scores on our processing speed measure significantly predicted higher quality choices on the CGT ($p < .01$) and BART ($p < .05$). Higher scores on our memory measure also significantly predicted higher quality choices on the CGT ($p < .05$), a result not evident when the entire participant sample was analyzed. No other pathways were significant. We note that

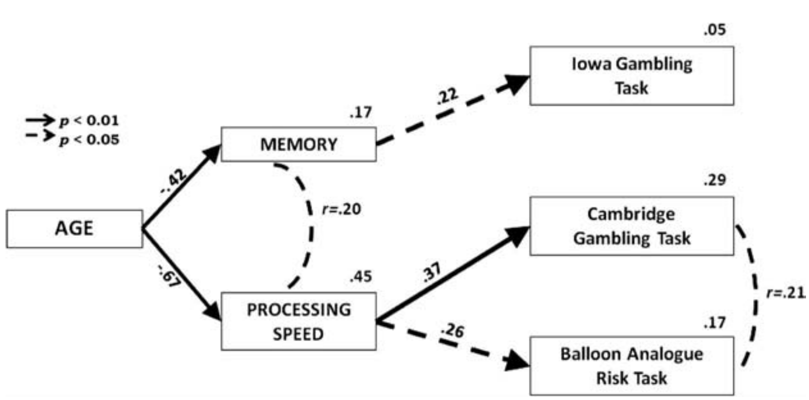


*Figure 2.* Final model indicating significant associations between model variables. Straight lines indicate significant paths, as identified by both model fitting and bootstrapping analysis, and curved paths indicate components of the model with significantly shared residual variance. Values on each path indicate its standardized coefficient; values above each box indicate proportion of variance explained by its predictors.

Table 5
*Path Parameters for the Final Model*

| Path | β |
|---|---|
| Age → processing | $-.669^{**}$ |
| Age → memory | $-.415^{**}$ |
| Age → IGT | .066 |
| Age → CGT | −.108 |
| Age → BART | −.155 |
| Processing speed → IGT | −.155 |
| Processing speed → CGT | $.373^{**}$ |
| Processing speed → BART | $.259^{*}$ |
| Memory → IGT | $.214^{*}$ |
| Memory → CGT | .155 |
| Memory → BART | .055 |

*Note.* IGT = Iowa Gambling Task; CGT = Cambridge Gambling Task; BART = Balloon Analogue Risk Task.
$^{*}$ $p < .05$. $^{**}$ $p < .01$.

because this analysis cuts our sample size in half, it may be underpowered given the number of paths in the model. Nevertheless, these post hoc results provide additional evidence that the observed relations between cognitive abilities and decision quality are robust, even within the older adult sample alone.

We swapped the order of cognitive factors and risk preferences in the model as a control analysis, thus treating the risk preferences as potential mediators between age and cognitive domains. This reduced the fit of our model, supporting the postulated direction of influence between these variables. We also controlled for the possibility that our results resulted from a statistical artifact: that the cognitive measures were better predictors than age simply because the former were normally distributed and the latter clustered around two discrete means. To do this, we randomized the processing speed and memory scores independently within each age-group, thus eliminating the potential links between those factors and risk scores but preserving their statistical properties (i.e., distribution of values within each group). When the path analyses were repeated, there were significant links from age to both the CGT and the BART (for each of three repetitions; *p*s $< .001$) but no mediating effects of cognitive abilities. This indicated that mediation was not an artifact of incorporating continuous variables into our model.

Thus, we conclude that differences between age-groups in decision quality—and the resulting changes in apparent risk preferences—are indirect effects mediated by age-related change in underlying cognitive domains.

## Discussion

We found no evidence for direct effects of adult age upon the quality of decision making. Instead, poorer performance on measures of cognition (e.g., processing speed and memory) predicted reduced decision quality, which was manifest in older adults' tendency toward risk-averse choices on the BART and selection of low-probability options on the CGT. These opposite-direction effects argue against the possibility that age has generalized effects on both cognitive capacities and risk aversion. Collectively, our results indicate that changes in cognitive abilities over the life span alter how older adults use information in decision making (i.e., impairing decision quality). Depending upon the task, these changes may be manifest as increased or decreased preferences for risk.

## Cognitive Mediators of Age Effects Upon Decision Making

The chief goals in cognitive aging research are to identify core cognitive abilities that change over the life span (Park et al., 1996; Salthouse, 2001) and to relate those changes to task performance. Aging has clear effects on fluid cognitive abilities, from processing speed and executive function to working memory and episodic retrieval, most of which decline systematically throughout the life span (Park et al., 1996). Yet, as demonstrated by Salthouse (Salthouse, 2001; Salthouse & Ferrer-Caja, 2003), these many diverse effects may result from age-related decline in a small number of underlying cognitive abilities. For example, using structural equation modeling, Salthouse and Ferrer-Caja (2003) found that individual differences specific to processing speed and memory, in addition to a common factor of generalized age-related decline, robustly predicted performance on a task battery. Moreover, the resulting model predicted age-related changes in two additional data sets, which provided strong evidence of its generalizability. These and other results (Madden, 2001; Salthouse, 1996, 2000) demonstrate that declines in processing speed, in particular, may play a key role in age-related deficits in performance.

Here, we adopted a similar framework to understand age-related differences in the quality of risky decision making. We found, consistent with prior research, that older adults exhibited decreased performance compared to younger adults on multiple psychometric tests, here collated into two factors of processing speed and memory. However, the present study is the first to demonstrate that those changes in cognition predict changes in overall decision quality and, in turn, task-specific effects on risk preference. In a compelling result, the robust age-related differences in decision making (see Table 5) disappeared completely when cognitive factors were included as mediating variables (see Figure 2).

Table 6
*Robustness Measures for Paths in the Final Model*

| Path | Estimated regression coefficients | 95% CI | Standardized regression coefficients |
|---|---|---|---|
| Age → processing | −0.10 | −.121 to −.081 | $-0.67^{**}$ |
| Age → memory | −0.05 | −.066 to −.028 | $-0.42^{**}$ |
| Age → IGT | 0.00 | *ns* | 0.07 |
| Age → CGT | 0.01 | *ns* | 0.11 |
| Age → BART | −0.01 | *ns* | −0.16 |
| Processing → IGT | −0.05 | *ns* | −0.16 |
| Processing → CGT | −0.15 | −.261 to −.042 | $-0.37^{**}$ |
| Processing → BART | 0.08 | .002 to .150 | $0.26^{*}$ |
| Memory → IGT | 0.09 | *ns* | 0.21 |
| Memory → CGT | −0.09 | *ns* | $-0.16^{*}$ |
| Memory → BART | 0.02 | *ns* | 0.06 |

*Note.* CI = confidence interval derived by bootstrapping (based on $N$ = 112 participants with complete observations); for clarity, nonsignificant paths are indicated with *ns.* IGT = Iowa Gambling Task; CGT = Cambridge Gambling Task; BART = Balloon Analogue Risk Task.
$^{*}$ $p < .05$. $^{**}$ $p < .01$.

Furthermore, the present results argue against the simple conception that aging has unilateral effects upon decision making (e.g., increased risk aversion). Instead, we found that increased age predicted reduced decision quality, which could be manifest in different ways according to task demands. The path analyses indicated that reduced performance on the processing speed factor predicted maladaptive risk-seeking decisions on the CGT, specifically the selection of options with a low probability of success. The same cognitive factor predicted maladaptive risk-averse decisions on the BART (i.e., too few pumps), in that individuals with low processing speed were unwilling to risk safe earnings against the possibility of a greater reward. These twin deficits—an inability to match choices to probabilities and a reluctance to place current holdings at risk—could together lead to real-world decision-making problems. For example, a reduced ability to evaluate probabilistic information would impair the ability to negotiate favorable financial terms and select investments with good risk-adjusted returns, whereas a tendency to maintain current investment holdings would limit portfolio diversity (Goetzmann & Kumar, 2008; Korniotis & Kumar, in press; Kumar, 2007). Simply put, these real-world problems may reflect limitations in cognitive capacities that are more common among older adults, rather than age-specific effects upon decision making.

## Implications for Studies of Decision Making and Aging

The present data exhibited distinct age-group differences on task performance: Increased age was associated with increased risk aversion on the BART and increased risk seeking on the CGT but had no net effect on the IGT. Considered by themselves, the results on the BART would be consistent with prior work indicating increased risk aversion in older adults (Bakshi & Chen, 1994; Jianakoplos & Bernasek, 1998; Okun, 1976; Riley & Chow, 1992; Wallach & Kogan, 1961), although the present results provide the first data on older adults' choices in this task. In light of our other findings, the BART results suggest that older adults—and particularly those with declines in processing speed—may express risk aversion by opting out of a decision scenario. Older adults often opt out of investment categories, such as equities, that involve potential risk (Kumar, 2007) and thus obtain lower annual investment returns (Korniotis & Kumar, in press). Older adults also often avoid making health care decisions, preferring instead to rely on others' advice (Deber et al., 1996; Mather, 2006; Okun, 1976; Wallach & Kogan, 1961; Zwahr et al., 1999).

Older adults selected significantly more low probability options on the CGT; this result replicated prior work using this task (Deakin et al., 2004). These choices reflect patently low quality decisions, given that the probabilities associated with each choice are visible at the time of the decision. One potential explanation for these choices is that they represent an increased tendency to anticipate the trials for which a lower probability option will be rewarded (Bereby-Meyer, Meyer, & Budescu, 2003; Wrase et al., 2007). We note that the CGT includes additional measures, notably the proportion of total points wagered on each trial. Deakin et al. (2004) found that older adults were less consistent in their adjustment of wagers according to objective probabilities. Because all CGT trials involve potentially positive expected value, inclusion of bet proportion into a measure of decision quality would require additional assumptions (e.g., the participants' estimate for the number of trials remaining). Thus, although our decision-quality measure involves only the selection of the higher probability option, future studies using other tasks could assess more complex effects of outcome probability on choice.

Finally, of the three decision-making tasks, the IGT (and similar paradigms) has been most frequently studied in older adults. We observed the intriguing result that higher memory scores, but not age, predicted selection of the advantageous decks in this task. This conflicts with one prior study that reported an increase in risk-seeking choices among older adults (Denburg et al., 2005). One possible explanation for this discrepancy lies in differences in the targeted age range. Whereas our older adults were at least 66 years old, and thus of typical postretirement age, the study by Denburg et al. used a lower threshold of 56 years. Financial risk aversion may systematically increase from pre- to postretirement cohorts, with a breakpoint around 64 years of age (Riley & Chow, 1992). This may reflect differences in income, current financial responsibilities, or some other factor, providing further evidence against age-specific effects upon risk attitudes. Another study that used a lower bound similar to that of our older adult group (65 years) also found no differences between IGT performance of older and younger adults (Wood et al., 2005).

## Conclusions and Limitations

Older adults make systematically different decisions—often resulting in demonstrably worse outcomes—than younger adults do. Whereas these differences are commonly attributed to increases in risk aversion, both prior research and the present study indicate that older adults may be either more risk averse or risk seeking depending on the decision context. Moreover, we demonstrate that age-related differences in decision-making performance reflect age-related differences in two underlying cognitive factors, one reflecting aspects of processing speed and another reflecting aspects of memory (particularly short-term semantic memory). Given the strength of the mediating role of cognitive decline in the model, other domains of cognitive functioning could contribute to decision making. However, we note our measures reflect fundamental cognitive processes often shown to influence additional sorts of performance (i.e., reasoning, spatial visualization), in addition to playing a central role in cognitive aging (Kramer & Madden, 2008; Park et al., 1996; Raz, 2000; Salthouse, 1985, 1993, 1996; Singer et al., 2003). One caveat comes from the properties of our tasks, which all measured aspects of decision making under economic risk (i.e., variance in potential monetary outcomes). Thus, the specific mappings between cognition and performance may not generalize to other tasks. However, we believe that the central conclusion—that cognitive factors mediate age-related differences in decision making—is likely to generalize to other domains of decision making, perhaps with different contributing cognitive factors.

These results provide new insight into the variability in decision preferences expressed by older adults, indicating that older adults' decisions may be highly sensitive to task context (i.e., how decision information is represented). Changes in the presentation of information—to enable heuristic strategies that reduce processing or memory demands—may in turn ameliorate age-related declines in adaptive decision making.