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Adaptivity in Decision-Making Strategies across Age: Process Insights and Implications

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ABSTRACT

Individuals increasingly face important decisions much later into their life. However, little is known about how aging systematically impacts the quality of these decisions, particularly in middle-aged older individuals between the ages of 45 and 65 relative to younger adults between the ages of 18 and 35. Across two independent studies using a risky-choice task, we found that younger adults preferred options that maximized the overall probability of winning while middle-aged older adults preferred options that maximized the largest gain. Critically, younger adults adapted their decision strategies to systematic changes in trial types, while middle-aged older adults were influenced by task-irrelevant factors like presentation format. Strikingly, these aging effects did not generalize to an annuity task in the second study, where middle-aged older adults demonstrated greater levels of deliberation and lesser susceptibility to task-irrelevant factors when choosing between annuities. Converging process data obtained using eye

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tracking corroborated these findings. These findings demonstrate that age-related changes in decision strategies across contexts may not always be optimal. This has important implications for generalizing the effects of age across tasks and for the development of interventions that facilitate better decision-making.

Introduction

THE world population is aging more quickly than ever before. Coupled with increasing life expectancies and declining birth rates, this phenomenon has forced middle-aged and elderly adults to make increasingly complex decisions regarding their retirement planning, healthcare and medical decisions, planning for decumulation of retirement savings, and decisions about will and estate planning, and others. Despite the potential impact of these decisions on the psychological well-being of both the individual and the society, relatively little is known about the effects of aging on these choices and how they are made. Additionally, the majority of studies examining decision-making focus on younger adults (ages 18–35) or elderly adults (ages 65 and above) and only a few studies evaluate decision preferences and strategies in middle-aged adults (ages 45–65). In this study, we sought to characterize preferences and decision strategies of these middle-aged older adults to those of younger adults, and to evaluate the consistency and generalizability of these findings across different decision-making tasks and contexts.

Effects of Age on Preferences

Several studies have sought to understand the effects of healthy aging on decision making (Carpenter and Yoon 2011; Li *et al.* 2013; Mata *et al.* 2007). In the domain of risk preferences, aging is often associated with risk-averse behavior (Deakin *et al.* 2004; Tymula *et al.* 2013). For example, aging was associated with reduced risk taking, poorer decisions, and also increased deliberation times in a computerized gambling task (Deakin *et al.* 2004). Similarly, older adults were found to be more risk-averse in a version of the Balloon Analog Risk Task (BART), making significantly fewer pumps relative to the younger adults (Henninger *et al.* 2010). In another study using gain and loss gambles, older adults were again found to be risk-averse, making decisions that resulted in the lowest expected monetary outcomes relative to the younger counterparts (Tymula *et al.* 2013). Older adults in this study also demonstrated increased irrationality, violating stochastic dominance in more than 25% of the trials. Finally, in a large-scale smartphone study conducted on over 25,000 individuals, the number of risky options chosen in trials with potential gains decreased with age, consistent again with risk-averse behavior (Rutledge *et al.* 2016).

However, a meta-analysis that reviewed several decades of research found no systematic differences in risk preferences across age (Mata *et al.* 2011). For example, the same older adults who were risk-averse in the BART were found to be more risk-seeking in the Columbia Gambling Task (Henninger *et al.* 2010). Similarly, several studies demonstrate that older adults make riskier and not risk-averse decisions in the Iowa Gambling task (Baena *et al.* 2010; Denburg *et al.* 2006; Zamarian *et al.* 2008). Therefore, it appears that the effects of aging on risk preferences vary significantly as a function of task characteristics and their learning requirements. Tasks that require participants to learn from recent experience and feedback like the Iowa Gambling Task and Columbia Gambling Task show differential patterns, relative to tasks where the performance does not depend on learning, like the BART (Mata *et al.* 2011).

A similar pattern also emerges from real-world decisions. Despite the popular belief that older adults are easily susceptible to scams and make poor decisions in life, the evidence is mixed. For example, studies involving real-world investment choices have found that older adults are less effective in applying their investment knowledge, and make poor financial decisions (Agarwal *et al.* 2007; Korniotis and Kumar 2011). However, there are a number of other studies that demonstrate that older adults perform just as well, or ever better than younger adults (Castel 2005; Hosseini *et al.* 2010; Samanez-Larkin *et al.* 2011). In sum, the pattern of age-related differences in decision-making is complex and is systematically influenced by the task environment and decision context.

Age-related Changes in Decision Strategies and Mechanisms

It is known that fluid capabilities like attention, executive control, and working memory decline with age (Salthouse 1996, 2000), while crystallized capabilities related to knowledge and experience are relatively spared (Park *et al.* 2002). The latter suggests that the accumulated experience over one's life span should lead older adults to make better decisions in certain contexts (Korniotis and Kumar 2011). Henninger *et al.* (2010) found that age-related changes in risk preferences across different tasks were fully mediated by cognitive capabilities like processing speed and memory. Li *et al.* (2013) demonstrated that greater crystallized intelligence in older adults compensated their lower levels of fluid intelligence in a variety of tasks including temporal discounting, financial literacy and debt literacy, making them better decision-makers. Similarly, using a unique dataset that combines measures of fluid and crystallized intelligence, it was shown that domain-specific knowledge and expertise provided an alternative route for older adults to make sound financial decisions (Li *et al.* 2015).

The effects of aging on decision preferences may also result from differences in the ability and motivation to obtain and process relevant information (Read and Read 2004; Wood *et al.* 2005). Older adults process lesser information overall, and often use non-compensatory attribute-based strategies (Johnson 1990; Johnson and Drungle 2000; Riggle and Johnson 1996). In one study specifically investigating the effect of aging on the ability to select decision strategies as a function of decision environment, older adults tended to look up lesser information and took longer to process them. They also used simpler and less demanding strategies like take-the-best overall compared to younger adults, consistent with a decline in their fluid abilities (Mata *et al.* 2007). Critically, older adults also adapted their information search and strategy to changes in the decision environment switching to compensatory strategies when required, but it remains unclear how these effects change as a function of different task characteristics, amount of information and type of information (Mata *et al.* 2007). In another study examining the role of task complexity on information search strategy using process measures, the authors found that adults of all ages (young, middle-aged, and older) used comparable decision strategies, and adapted them to changes in complexity of the task (Queen *et al.* 2012). Consistent with Mata and colleagues, this study also found that older adults utilized simpler and smaller sets of information that reflected the most important attributes for them.

In summary, older adults seem to have a repertoire of strategies that they adaptively choose from, depending on task complexity and their motivation. These studies also suggest that the tendency of older adults to generally select cognitively simpler strategies might not always be a limitation, especially if these strategies fit the decision environment better (Mata *et al.* 2007). However, few have systematically explored the effectiveness of these different decision strategies across tasks and contexts, particularly when there is not one objectively correct strategy to begin with. For example, how do older adults respond if the changes in decision context are superficial and irrelevant for the main task? Are there boundary conditions where the use of certain decision strategies leads to suboptimal choices in older adults?

In this paper, we address three key objectives. First, we use a complex risky-choice task involving decisions between multiple complex mixed gambles to explore age-related changes in decision strategies (Payne 2005). Most prior work on risk preferences use simple decisions between a two-outcome risky gamble and a sure option, limiting the possibilities for elucidating systematic differences in decision strategies. The risky-choice task used here facilitates the adaptive use of distinct decision strategies across trials (Venkatraman *et al.* 2014).

Second, we seek to systematically characterize how aging affects decision-making strategies within the same individual across different presentation formats and tasks. For example, in addition to exploring the adaptive use of decision strategies across task-relevant changes in the decision environment similar to previous studies (Mata *et al.* 2007; Queen *et al.* 2012), we also seek to understand how individuals respond to task-irrelevant changes like presentation format. This provides valuable insights into whether these changes are adaptive or maladaptive.

Lastly, we focus on middle-aged older adults between the ages of 45 and 65 as our older sample in this study rather than adults above the age of 65. We focus on this group because they are arguably faced with some of the most crucial and significant decisions in an individual's life span, and yet not studied as often. In one previous study that compared these middle-aged adults to younger and older groups, no differences were found in both the information search patterns and decision preferences across groups (Queen *et al.* 2012). However, the focus was primarily on comparing older adults with the younger adults. Here, we focus primarily on middle-aged older adults (henceforth referred to as the older adults in this manuscript) and compared their decisions with younger adults.

Study 1

In this study, we focus on a complex risky-choice task where each gamble consists of three mixed outcomes (one gain, one loss, and one intermediate), each with its own probability. Participants choose between one of three gamble alternatives (Gain maximizing or Gmax alternative that is associated with the best possible gain outcome, Loss minimizing or Lmin alternative associated with the worst possible loss outcome, and "intermediate" alternative associated with superior value for the intermediate outcome). The three alternatives were constructed by improving one outcome from a three-outcome base gamble (Payne and Venkatraman 2011; Venkatraman *et al.* 2009, 2014; Yoon *et al.* 2017). In some trials (Pwin-available), the intermediate alternative is associated with a greater overall probability of winning. In other trials (Pwin-unavailable), there is no difference in overall probability of winning across alternatives (Figure 1).

In previous studies using variants of this task, participants (younger adults) showed a strong preference for the intermediate alternative in Pwin-available trials, maximizing the overall probability of winning (Pwin choice; Payne 2005; Venkatraman *et al.* 2009, 2014). However, they switched to other alternatives in Pwin-unavailable trials. Therefore, we predict that younger adults will show similar adaptive preferences in this task, showing a strong bias for Pwin choices only in Pwin-available trials. On the other hand, if older adults were indeed risk-averse, we

	0.33	0.33	0.33
G1 (Gmax)	\$85	-\$10	-\$75
G2 (Pwin)	\$65	\$10	-\$75
G3 (Lmin)	\$65	-\$10	-\$55

Pwin-available

	0.33	0.33	0.33
G1 (Gmax)	\$80	-\$25	-\$70
G2 (Inter)	\$65	-\$10	-\$70
G3 (Lmin)	\$65	-\$25	-\$55

Pwin-unavailable

Figure 1: **Examples of Stimuli used in Study 1.** An example of Pwin-available and Pwin-unavailable trial from the risky-choice task. All gambles had equal expected value in both trial types. In Pwin-available trial, the intermediate alternative (G2, Pwin) was associated with a higher overall probability of winning (0.66) relative to the other alternatives (0.33). However, in the Pwin-unavailable trial, all alternatives were associated with the same overall probability of winning (0.33). Participants indicated their preference by pressing an appropriate button on the keyboard. Labels for each of the alternatives are shown for display purposes only.

would predict a greater preference for Lmin or Pwin choices, relative to Gmax choices. However, increased positivity bias (Carstensen 1992, 2006) and risk-seeking behavior would predict a greater preference for Gmax choices, similar to findings observed following sleep deprivation in a similar task (Venkatraman *et al.* 2011). Critically, we also evaluate whether older adults adapt to changes in the task environment or whether they use the same strategy across both conditions (i.e., show no differences between the Pwin-available and Pwin-unavailable trials).

Methods

Participants: A total of 51 adults participated in this study from the general Philadelphia community, including 27 older (mean age $\pm$ SD: 54.07 ± 5.48 years) and 24 younger adults (mean age $\pm$ SD: 25.46 ± 4.40 years). We focused primarily on individuals who were between the ages of 45 and 65 for the older cohort in our study because they are most concerned about financial security and are contemplating critical real-world decisions like those involving retirement planning. The Institutional Review Board of the University approved all studies.

Stimuli: In each trial, participants had to choose between three different mixed gambles, presented in a 4×4 grid format (Figure 1). The magnitudes of the outcomes varied across trials, but probabilities and expected values were equal across the three alternatives within a trial. The outcomes of the intermediate alternative were chosen in such a way that in some trials, the alternative was associated with a higher overall probability of winning (Pwin-available trials) relative to the other two alternatives, while in other trials, all alternatives had the same overall probability of winning (Pwin-unavailable trials). The outcomes in each gamble were always rank-ordered from gains to intermediate outcomes to losses. In other words, the first column always contained the gain outcomes of the three alternatives, and the last column always contained the loss outcomes. However, the order of alternatives was randomized across trials. After completing two practice problems to familiarize themselves with the decision environment, participants completed four problems in each of the two trial types in a randomized manner.

Exclusions: A total of six responses, where the response time was shorter or longer than three standard deviations from the mean, were excluded from the analysis.

Results

The choice proportion for each group in each condition is summarized in Table 1. Overall, younger adults showed an increased preference for the intermediate alternative while older adults showed a greater preference for Gmax choices (Table 1). To explore the adaptive nature of choices across groups, we regressed the choice of intermediate alternative (1: intermediate alternative choice vs. 0: other alternative choice) on group (Old vs. Young; between), interacted with trial type (Pwin-available vs. Pwin-unavailable; within) using a multilevel linear probability model to account for the repeated nature of trials within participant. The main effects of group ($b = -0.20$, $SE = 0.08$, $z = -2.55$, $p = .011$) and trial type ($b = -0.19$, $SE = 0.06$, $z = -3.05$, $p = .002$) were statistically significant, showing that younger adults chose the intermediate alternatives more than older adults did, and that participants chose the intermediate alternatives more in the Pwin-available trials than in the Pwin-unavailable trials. We also found a marginally significant interaction between group and trial type ($b = 0.16$, $SE = 0.08$, $z = 1.84$, $p = .066$). Consistent with previous studies using a similar task (Venkatraman *et al.* 2014; Yoon *et al.* 2017), younger adults showed a stronger preference for the intermediate alternative in the Pwin-available

Table 1: Summary of response times and choice proportions across conditions for the risky-choice task in Study 1. Standard deviations are presented in the parentheses.

	Younger adults		Older adults	
	Pwin available	Pwin unavailable	Pwin available	Pwin unavailable
Response Time (sec.)	13.30 (6.47)	16.20 (8.21)	13.74 (9.96)	13.45 (8.74)
Choice Share (%)				
Gmax	27.66	35.79	45.79	51.89
Intermediate	53.19	33.68	32.71	29.25
Lmin	19.15	30.53	21.50	18.87

trials (53.19%) than in the Pwin-unavailable trials (33.68%; contrast for trial type: $\chi^2(1) = 9.30$, $p = .002$). However, preferences in older adults did not vary by trial type (Pwin available = 32.71% vs. Pwin-unavailable = 29.25%; $\chi^2(1) = 0.31$, $p = .579$), demonstrating that they were less adaptive than younger adults.

The lack of adaptivity in older adults was corroborated further by response time data (Table 1). Using a 2 (trial type: Pwin-available vs. Pwin-unavailable; within) $\times$ 2 (group: young vs. old; between) multilevel linear regression analysis, we found no significant main effect of group ($b = 0.40$, $SE = 2.33$, $z = 0.17$, $p = .864$), but found a significant main effect of trial type ($b = 2.93$, $SE = 0.87$, $z = 3.37$, $p = .001$) and a significant interaction between group and trial type ($b = -3.20$, $SE = 1.19$, $z = -2.68$, $p = .007$). Younger adults spent significantly more time in Pwin-unavailable trials than in Pwin-available trials ($\chi^2(1) = 11.37$, $p < .001$) consistent with previous studies using a similar task (Venkatraman *et al.* 2014), but there were no differences in response times for older adults between the two conditions ($\chi^2(1) = 0.11$, $p = .740$).

Discussion

We observed two critical differences between younger and older middle-aged adults in the risky-choice task. First, younger adults demonstrated a stronger preference for maximizing the overall probability of winning, while older adults maximized the highest gain. Second, whereas younger adults adapted their preferences to changes in the trial types, older adults' preferences did not vary across the different trial types. Therefore, unlike previous studies (Mata *et al.* 2011; Queen *et al.* 2012), older adults did not seem to adapt their decision strategies to changes in the decision environment.

At the outset, the pattern of increased preference for Gmax choices in older adults is consistent with optimistic and risk-seeking behavior. This is consistent with socioeconomic selectivity theory (SST; Carstensen 1992, 2006), which argues that older adults place greater priority on goals related to well-being while placing relatively less emphasis on emotionally riskier goals, leading to a positivity bias (Carstensen and Mikels 2005). Our findings represent a similar positive bias in older adults, leading to the preference for alternatives that maximize the highest gain. However, an alternative explanation posits that older adults use simpler decision strategies and hence merely overweight the information presented in the earlier column (i.e., first column). Since the leftmost column was always gain attributes in this study, it leads older adults to choose the alternative that is better on this attribute, and be less sensitive to changes in trial types.

We explored the underlying processes in an independent follow-up study using eye tracking. We were particularly interested in how younger and older adults adapted to systematic changes in task-relevant decision variables, as well as task-irrelevant changes in presentation format across trials. If older adults were using simpler strategies (i.e., focusing on the outcomes in the first column), we predicted that they would be more likely to be influenced by superficial changes in the presentation format, while younger adults would make consistent choices across the different presentation formats. However, if their preferences were related to increased risk-seeking behavior, older adults should continue to show increased preference for Gmax choices regardless of presentation order.

In the follow-up study, participants also completed a second financial decision-making task where they had to choose between multiple annuities that varied on different attributes. Since both tasks had a similar structure (choosing between multiple alternatives that varied on different attributes), we tested whether age-related changes in the decision-making strategies were consistent across both tasks in the same session. For instance, if participants are influenced by the order in which information is presented in the risky-choice task, are they also influenced by presentation order in the annuity task? Similarly, if participants are more likely to use attribute-based decision strategies in one task, do they continue to do so in the second task? These insights have important implications for the generalizability of aging effects across different decision-making tasks and domains.

Study 2

Methods

Participants: A total of 56 adults participated in this study from the general Philadelphia community. This included 27 older (mean age $\pm$ SD: 50.67 ± 6.03 years) and 29 younger adults (mean age $\pm$ SD: 22.65 ± 5.29

years; mean age is computed based on 17 participants as exact age information was not recorded for 12 younger adults due to a computer error. However, we can still categorize them as younger adults based on information from the recruiting phase). They completed two different tasks while seated in front of a Tobii T60XL eye tracker. They completed the risky-choice task similar to Study 1 first, followed by an annuity task. We used a 9-point calibration for the eye tracker at the beginning of the study. All participants were re-calibrated before the beginning of the annuity task. Each session lasted an hour approximately, and participants were compensated $15 for their time.

Risky-choice task: Participants completed 16 trials (eight Pwin-available and eight Pwin-unavailable) following a slightly modified version of the risky-choice task from Study 1. We randomized both the alternatives and rank ordering of outcomes across the trials in this study (Figure 2a). In

	0.33	0.33	0.33
G1 (Gmax)	-$10	-$75	$85
G2 (Inter)	$10	-$75	$65
G3 (Lmin)	-$10	-$55	$65

Pwin-available, ordered-random trial

	0.33	0.33	0.33
G1 (Inter)	-$10	-$70	$65
G2 (Lmin)	-$55	$65	-$25
G3 (Gmax)	$80	-$25	-$70

Pwin-unavailable, fully-random trial

(a)

	PC	CR	AI	MP
A1	5 years	AAA	$400	$470
A2	15 years	A	3%	$650
A3	10 years	AA	$200	$560

Risk-first

	MP	AI	CR	PC
A1	$470	$200	A	15 years
A2	$650	0%	AA	10 years
A3	$560	$400	A	0 years

Amount-first

(b)

Figure 2: **Exemplars of Stimuli used in Study 2.** (a) An example of Pwin-available ordered-random trial (ordered by intermediate, loss, and gain outcomes), and Pwin-unavailable fully-random trial from the risky-choice task. All gambles had equal expected value in both trial types, and the labels for alternatives are shown for display purposes only. (b) An example trial from the annuity task for the risk-first and amount-first presentation formats. In each trial, participants had to choose between one of the three annuities presented, or to self-manage their investments.

ordered-random trials, the columns were randomized but they remained grouped by gains, losses, or intermediate outcomes. There were three possible column orders: (i) Gain, intermediate, loss; (ii) intermediate, loss, Gain; and (iii) Loss, Gain, intermediate. Additionally, we had a fourth type where all items were completely randomized. In these *fully-random* trials, the individual columns were no longer grouped by specific outcomes. Among the 16 trials, four trials were randomly assigned to *fully-random* condition (two Pwin-available and two Pwin-unavailable trials).

Annuity task: Despite guaranteed payment for life, people are often reluctant to purchase annuities — a phenomenon known as the *annuity puzzle* (Barberis 2013; Hu and Scott 2007). Several studies have focused on understanding the mechanisms underlying this annuity puzzle (Payne *et al.* 2013; Shu *et al.* 2016). We used a modified version of the annuity task from Shu *et al.* (2016) to match the structure of the risky-choice task. In each trial, participants had to choose between three different annuities, based on information about four different attributes (CR: company rating, PC: period certainty, AI: annual increment, MP: monthly payment). Each attribute had between three and five different levels (see Web Appendix 1), and the levels were determined based on a previous study using a similar task. Participants were briefed extensively about annuities and the corresponding attributes at the beginning of the task, and answered a series of questions to demonstrate their understanding of the same. This allowed us to equate the basic level of knowledge about annuities across the two groups of participants.

Participants completed a total of 20 annuity decisions. Across trials, we also varied the presentation order of attributes similar to the risky-choice task (Figure 2b). In one set of 10 trials (*risk-first format*), the risk-related attributes (CR, PC) were presented in the earlier columns relative to the amount-related attributes (AI, MP). In the second set of 10 trials (*amount-first format*), the amount-related attributes were presented earlier. The order was counterbalanced across participants. We also counterbalanced the relative positions of risk-related (CR and PC) and amount-related (MP and AI) attributes across participants. However, for all analyses, we collapse across these additional randomizations, and focus on the two main presentation formats: risk-first and amount-first.

Exclusions: We excluded responses in which eye-tracking data was not recorded or where the response time was shorter or longer than three standard deviations from the mean in each task. For the final analysis, a total of 60 responses (7% of all responses; no eye-tracking signal: 46 responses, RT outliers: 14 responses) from risky-choice task and a total of 97 responses (9% of all responses; no eye-tracking signal: 78 responses, RT outliers: 19 responses) from the annuity task were excluded. This led to the exclusion of two older respondents' full responses from the analyses.

Results

Risky-choice Task: All choice preferences are summarized in Table 2. For the analysis, we ran a 2 (group: young vs. old; between) × 2 (trial type: Pwin-available vs. Pwin-unavailable; within) multilevel linear probability regression analysis. Across all trials, younger adults showed a strong preference for intermediate alternative while older adults preferred the Gmax alternative overall ($b = -0.17$, $SE = 0.06$, $z = -2.95$, $p = .003$), and participants, in general, chose the intermediate alternative more in the Pwin-available trials than in the Pwin-unavailable trials ($b = -0.18$, $SE = 0.04$, $z = -4.13$, $p < .001$). As seen from Table 2, younger adults showed a greater preference for the intermediate alternatives in Pwin-available trials relative to Pwin-unavailable trials, while older adults' preferences did not vary across trial types. However, this interaction between group and trial type was not significant ($b = 0.08$, $SE = 0.06$, $z = 1.22$, $p = .222$).

The response time data showed a significant interaction between group and trial type ($b = -1.26$, $SE = 0.59$, $z = -2.15$, $p = .032$) using a 2 (group: young vs. old; between) × 2 (trial type: Pwin-available vs. Pwin-unavailable; within) multilevel linear regression analysis (Table 3). Further contrasts revealed that younger adults spent longer time in Pwin-unavailable trials than Pwin-available trials ($\chi^2(1) = 22.72$, $p < .001$), while older adults did not show any difference between the two trial types ($\chi^2(1) = 2.24$, $p = .135$), replicating finding from Study 1. Together, these results suggest that younger adults were more adaptive in their decision strategies across trial types.

We next examined the effect of trial type and randomization formats using a 2 (group: young vs. old; between) × 2 (trial type: Pwin-available

Table 2: Choice proportions (%) across trial types and presentation formats for the risky-choice task in Study 2.

	All				Ordered-random				Fully-random			
	Young		Old		Young		Old		Young		Old	
Pwin	Available	Unavai-lable	Available	Unavai-lable	Available	Unavai-lable	Available	Unavai-lable	Available	Unavai-lable	Available	Unavai-lable
Gmax	17.41	32.00	38.66	46.63	17.96	33.33	38.10	51.39	15.79	27.78	40.43	32.65
Intermediate	57.14	39.11	39.69	29.53	55.09	39.18	42.86	25.00	63.16	38.89	29.79	42.86
Lmin	25.45	28.89	21.65	23.83	26.95	27.49	19.05	23.61	21.05	33.33	29.79	24.49

Table 3: Response time (in seconds) in the risky-choice task in Study 2 (standard deviations are presented in the parentheses).

	All		Ordered-random		Fully-random	
	Young	Old	Young	Old	Young	Old
Pwin-available	11.32	8.08	11.21	7.84	11.66	8.73
	(5.10)	(2.52)	(5.04)	(2.48)	(6.33)	(3.52)
Pwin-unavailable	13.27	8.75	13.27	8.61	13.50	9.31
	(6.84)	(3.61)	(6.91)	(3.67)	(7.58)	(4.29)

vs. Pwin-unavailable; within) × 2 (format: ordered-random vs. fully-random; within) multilevel linear probability regression analysis for choice of intermediate alternative. We found a significant three-way interaction ($b = 0.40$, $SE = 0.15$, $z = 2.67$, $p = .008$). Younger adults consistently preferred the intermediate alternatives in Pwin-available trials than in Pwin-unavailable trials regardless of presentation formats, whereas older adults showed a higher preference for the intermediate alternative in Pwin-available trials, but only when the presentation format was ordered-random. This suggests that older adults were influenced to a greater extent by task-irrelevant features like presentation format.

In a follow-up analysis, we tested whether older adults were influenced more by the information presented in the earlier columns using a 2 (group: young vs. old; between) × 2 (presentation order: gain-first vs. intermediate-first; within) multilevel linear probability regression analysis, restricting the data to only the Pwin-available trials from the ordered-random format. Again, we found a significant interaction effect ($b = 0.25$, $SE = 0.13$, $z = 1.96$, $p = .050$), suggesting that the proportion of Pwin choices were consistent across both presentation orders in younger adults, while older adults chose the Pwin option more often when the intermediate outcomes were presented in the earlier column (Table 4).

We also found a similar pattern in the eye-tracking data for Pwin-available trials (Figure 3, see also Web Appendix 2 for a summary of other eye-tracking measures). The results of a 2 (group: young vs.

Table 4: Choice proportions (%) for the Pwin-available trials as a function of presentation order in the risky-choice task in Study 2.

	Young		Old	
	Gain-first	Intermediate-first	Gain-first	Intermediate-first
Gmax	16.13	18.97	41.51	38.00
Pwin	59.68	50.00	33.96	48.00

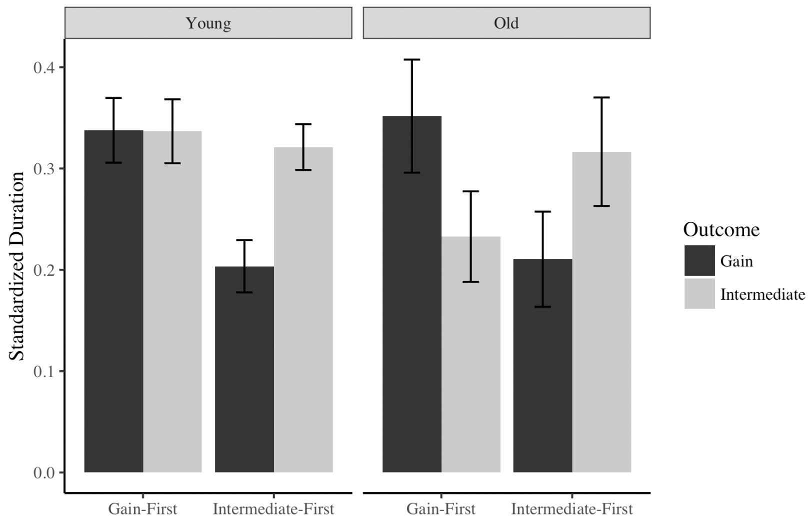

Figure 3: **Summary of standardized eye-gaze duration on each attribute in the risky-choice task in Study 2.** Error bars indicate 95% confidence intervals. Processing in older adults was significantly influenced by the order in which information was presented, as indicated by the increased attention paid to the attributes presented in the earlier columns.

old; between) $\times 2$ (presentation order: gain-first vs. intermediate-first; within) multilevel linear regression showed slightly different patterns for each outcome (gain and intermediate). For the gain outcomes, we found a significant main effect of presentation order ($b = -0.14$, $SE = 0.02$, $z = -6.24$, $p < .001$), but the main effect of age group ($b = 0.02$,

$SE = 0.03$, $z = 0.70$, $p = .483$) and the interaction ($b = -0.001$, $SE = 0.03$, $z = -0.03$, $p = .973$) were not significant. Participants processed gain outcomes more when the gain outcomes were presented in the first columns than they were not, but this pattern did not differ between young and older adults.

For the intermediate outcomes, we found significant main effect of age group ($b = -0.10$, $SE = 0.02$, $z = -4.26$, $p < .001$) and significant interaction between age group and presentation order ($b = 0.08$, $SE = 0.03$, $z = 2.66$, $p = .008$), but the main effect of presentation order was not statistically significant ($b = -0.01$, $SE = 0.02$, $z = -0.31$, $p = .757$). Younger adults processed the intermediate outcomes in both presentation orders similarly ($\chi^2(1) = 0.10$, $p = .757$), while older adults spent longer time on the intermediate outcomes when the intermediate outcomes were presented in the first columns than they were presented in later columns ($\chi^2(1) = 11.33$, $p < .001$).

Annuity task: For this analysis, we regressed purchase decisions (purchase annuity = 1 vs. self-management = 0) on group (young vs. old; between) and presentation order (risk-first vs. amount-first; within) using a multilevel linear probability model. Overall, older adults and younger adults purchased annuities similarly ($b = 0.07$, $SE = 0.05$, $z = 1.53$, $p = .127$), and purchase rates were lower when amount-related attributes were presented in early columns ($b = -0.05$, $SE = 0.03$, $z = -1.94$, $p = .052$). We found a significant interaction between group and presentation order ($b = 0.08$, $SE = 0.04$, $z = 2.13$, $p = .033$), showing that purchase differences between younger and older adults was greater when amount-related attributes (MP, AI) were presented first ($\chi^2(1) = 11.33$, $p < .001$), relative to risk-related attributes (CR, PC) first ($\chi^2(1) = 2.33$, $p = .127$; Table 5).

A 2 (group: young vs. old; between; between) $\times$ 2 (format: risk-first vs. amount-first; within) multilevel linear regression analysis of response time data also showed a significant interaction effect between age group and format ($b = 1.69$, $SE = 0.67$, $z = 2.53$, $p = .012$). Both groups spent more time when risk-related attributes were presented first ($b = -2.68$, $SE = 0.45$, $z = -5.91$, $p < .001$), but the difference in response time between the two presentation formats were greater for younger adults ($\chi^2(1) = 34.92$, $p < .001$) than that for older adults ($\chi^2(1) = 4.13$, $p = .042$; Table 5). Therefore, younger adults showed

Table 5: Summary of annuity purchase rates and response times across different presentation formats for the annuity task in Study 2 (standard deviations are presented in the parenthesis).

	Overall	Risk-first	Amount-first
Purchase Rate (%)			
Young	80.40	83.03	77.74
Old	91.95	90.30	93.62
Response Time (sec.)			
Young	11.43	12.77	10.09
	(5.32)	(5.37)	(5.01)
Old	11.27	11.78	10.75
	(4.32)	(4.00)	(4.65)

greater differences across presentation formats than older adults, unlike the risky-choice task where we observed the opposite pattern.

We next turned to process measures obtained using eye tracking (see Web Appendix 3 for summary). Specifically, we examined whether older adults were more influenced by the earlier attributes, similar to the risky-choice task. This would demonstrate that decision strategies are indeed consistent and generalizable across tasks and decision domains. We computed the standardized duration for each attribute across formats and looked for the effects of age using a 2 (group: young vs. old; between) $\times$ 2 (format: risk-first vs. amount-first; within) multilevel linear regression for each attribute separately (Table 6).

Generally, both younger and older groups spent longer time when the attributes were presented in earlier columns than later columns (consistent with reading order). This pattern was consistent across the four attributes (Z values > 5, p values $< .001$). However, we did not find a significant interaction between age group and format for company rating ($b = 0.01$, $SE = 0.01$, $z = 0.84$, $p = .399$) or annual increment ($b = 0.01$, $SE = 0.01$, $z = 1.16$, $p = .247$), but a significant interaction for monthly payment ($b = -0.05$, $SE = 0.01$, $z = -3.52$, $p < .001$) and period certainty ($b = 0.02$, $SE = 0.01$, $z = 2.33$, $p = .020$). Both younger adults and older adults spent more time on monthly payment

Table 6: Mean standardized eye-gaze durations for each attribute as a function of presentation format in the annuity task in Study 2 (standard deviations are presented in the parentheses). CR = Company Rating, PC = Period Certainty, MP = Monthly Payment and AI = Annual Increment.

		Standardized Duration			
		CR	PC	MP	AI
Young	Risk-first	0.182	0.209	0.223	0.206
		(0.06)	(0.06)	(0.08)	(0.06)
	Amount-first	0.144	0.154	0.307	0.263
		(0.06)	(0.08)	(0.07)	(0.07)
Old	Risk-first	0.158	0.163	0.227	0.164
		(0.07)	(0.07)	(0.11)	(0.08)
	Amount-first	0.136	0.131	0.254	0.238
		(0.09)	(0.07)	(0.08)	(0.12)

when it was presented in earlier columns than when it was presented in later columns (younger adults: $\chi^2(1) = 76.82$, $p < .001$ vs. older adults: $\chi^2(1) = 11.00$, $p < .001$), but surprisingly the difference was greater in younger adults than in older adults. Similarly, both younger adults and older adults spent longer time on period certainty when it was presented in earlier columns than when it was presented in later columns (younger adults: $\chi^2(1) = 59.84$, $p < .001$ vs. older adults: $\chi^2(1) = 15.89$, $p < .001$), but again the difference was greater in younger adults than it was in older adults. In summary, process results suggest that both groups were sensitive to changes in presentation format. However, in contrast to the risky-choice task, younger adults were influenced by these task-irrelevant changes to a greater extent than older adults.

Consistency across tasks: We examined the consistency of decision strategies across the two tasks (Table 7). We ran a 2 (group: young vs. old; between) $\times$ 2 (task: risky-choice vs. annuity; within) mixed ANOVA for three different process measures: response time, Payne index, and pupil dilation. The Payne Index (PI) is a simple way to represent information search pattern (Payne *et al.* 1988), and it

Table 7: Cross-task consistency between the risky-choice task and the annuity task in Study 2 (standard deviations are presented in the parentheses). RT = Response time, PI = Payne Index, PS = Mean pupil size.

	Young			Old		
Task	RT	PI	PS	RT	PI	PS
Risky-choice	12.324	−.315	4.151	8.422	−.190	3.426
	(5.85)	(0.25)	(0.58)	(2.96)	(0.29)	(0.64)
Annuity	11.444	−.136	3.963	11.275	−.142	3.334
	(5.05)	(0.27)	(0.62)	(4.18)	(0.24)	(0.60)

is calculated by (# of alternative-wise search − # of attribute-wise search)/(# of alternative-wise search + # of attribute-wise search). Therefore, the PI has a range from −1 to 1 in which a negative sign indicates more attribute-wise search while a positive sign indicates more alternative-wise search. We also measured pupil dilation as participants processed the information. As several studies have shown, the pupil dilates when participants engage in tasks that require mental effort (Alnaes *et al.* 2014; Kahneman and Beatty 1966; Porter *et al.* 2007). For example, Kahneman and Beatty (1966) found that the pupil dilates as a result of increased working memory load, and more recent studies have found that pupil size indicates search difficulty in visual search (Porter *et al.* 2007) and multiple-object tracking (Alnaes *et al.* 2014). We use pupil dilation as an index of effort and engagement in the current study.

We found a significant interaction between age group and task for response times (Table 7; $F(1, 52) = 16.07$, $p < .001$). Younger adults took slightly longer than older adults took to complete the risky-choice task ($F = 35.11$, $p < .001$), but there was no difference in the annuity task ($F = 0.07$, $p = .799$). For the PI, both groups showed more attribute-based search pattern in the risky-choice task than in the annuity task ($F(1, 52) = 8.15$, $p = .006$). We also found a greater difference between the two tasks for younger adults (highly attribute-based search pattern for younger adults in the risky-choice task than in the annuity task) than for older adults, but the interaction effect was not significant ($F(1, 52) = 2.75$, $p = .104$). For pupil dilation, younger adults showed greater pupil dilation than older adults ($F(1, 52) = 16.95$, $p < .001$), and both groups showed greater pupil dilation in the risky-choice task than annuity task. However, we did not find a significant interaction between group and task ($F(1, 52) = 2.72$, $p = .105$), though the difference between tasks was slightly larger for younger adults than it was for older adults.

Discussion

Similar to Study 1, younger adults demonstrated a greater preference for maximizing the overall probability of winning while older adults showed greater preference for gain maximizing choices. Critically, older adults were influenced by superficial changes in presentation format unlike younger adults, who adapted to changes in task-relevant variables. Process data from eye tracking corroborated these findings, with older adults spending more time processing attributes that were presented in earlier columns. These findings argue that older adults used simpler decision strategies focusing on information presented in earlier columns, leading them to be susceptible to task-irrelevant aspects like presentation order and less adaptive to other task-relevant changes.

In contrast, we found that older adults were influenced to a lesser extent by task-irrelevant changes in presentation order for the annuity task relative to younger adults. First, they showed lesser difference in purchase rates and response times between the two formats, relative to younger adults. Second, though both younger and older adults spent longer time processing attributes presented in earlier columns, this pattern was weaker for older adults. These findings suggest that the effects of age on decision strategies are strongly modulated by task and decision domains, even within the same individuals. Finally, we also found greater differences in overall processing strategies across the two tasks for younger adults relative to older adults.

General Discussion

In this manuscript, we explored the effects of age on preferences and decision strategies, and its generalizability across changes in decision context and tasks within the same individual. We found that older adults between the ages of 45 and 65 were less adaptive in their decision-making strategies across task-relevant changes in the trial types relative to the younger adults in the risky-choice task. Older adults were also influenced to a greater extent by bottom-up and task-irrelevant features like the order in which information was presented for the risky-choice task, but to a much lesser extent for the annuity task. These findings suggest that motivation and engagement at the task level may play an important role in their preferences and decision strategies.

Across two independent studies, younger adults showed a greater preference for the choice that maximized the overall probability of winning. Consistent with previous studies using a similar paradigm, younger adults demonstrated adaptive preferences, switching their decision strategies across trial types (Venkatraman *et al.* 2009, 2014). On the other hand, older adults showed higher preference for gain-maximizing choices. Critically, older adults were more sensitive to superficial changes in presentation format. While preferences in younger adults were robust to these changes, older adults were more influenced by the order in which information was presented. This was corroborated by process data from eye tracking, which suggested increased attention paid to the information presented in earlier columns (Fishburn 1974; Montgomery and Svenson 1976; Payne *et al.* 1988). Together, our findings suggest that older adults used simpler attribute-based strategies like choosing the superior alternative based on information in the earlier columns. Moreover, older adults did not adapt their decision strategies sufficiently to changes across trial types in the risky-choice task.

In the second study, we focused specifically on the effects of age on preferences for annuities. We first found significantly higher purchase rates relative to those found by Shu *et al.* (2016). This may be because we ran our studies in the laboratory instead of using an online sample, which was used in the earlier study. Though the smaller laboratory samples make it difficult to estimate the utilities of various attributes using a full conjoint model, corresponding process data demonstrated that both younger and older adults were influenced by presentation format in this task. Critically, younger adults were more susceptible to these changes in presentation order. Though both younger and older adults spent longer time processing attributes presented in earlier columns relative to later columns, this pattern was stronger for younger adults. Younger adults also spent longer time on the monthly payment and period certainty when they were presented in earlier columns than when they were presented in later columns, but older adults showed no such difference. Therefore, the susceptibility of older adults to task-irrelevant features did not generalize across tasks. These findings suggest that motivation and engagement at the task level can play an important role in influencing age-related changes in decision strategies.

Several past studies have demonstrated differential effects of age on decision preferences, suggesting a similarly important role for task and motivation (Finucane *et al.* 2005; Löckenhoff and Carstensen 2007; Mather and Carstensen 2005; Wood *et al.* 2005). Yet, none of these studies compared these effects in the same session across different tasks. In this study, in addition to looking at age-related changes in decision preferences across two different tasks, we also focused on the underlying strategies characterized using process data. First, younger adults took slightly longer than older adults for the risky-choice task, but were faster in the annuity task. Second, younger adults showed greater pupil dilation than older adults, and this difference was greater for the risky-choice task. Finally, using the Payne Index, younger participants showed more attribute-based processing for the risky-choice task than older adults, but both groups showed similar attribute-based processing for the annuity task. Critically, these differences across tasks cannot be attributed to differences in cognitive capabilities, given that they occur within the same individual in the same session.

Overall, the strategies used by older adults were more homogenous across trial types and tasks than the strategies used by younger adults were — they showed fewer changes in decision strategies across trial types in the risky-choice task, and they also showed fewer differences in the processing measures across tasks in Study 2. One could argue that the differences between younger and older adults in the annuity task may be related to the decreased familiarity of younger adults with annuity attributes, leading them to spend more time making sense of their attributes. In contrast, older adults may have been more fluent at processing them independent of presentation format, but both groups had to learn basic details about annuities, and we ensured that they had similar levels of comprehension prior to the actual task. Second, younger adults did not take significantly longer in the annuity task. Therefore, we believe that older adults may have generally been more engaged in the annuity task because the task is more relevant to them relative to a gambling task. Younger adults on the other hand may not have been as engaged in the annuity task because they are less familiar and concerned with annuities and retirements at this stage of their lives.

In summary, our findings suggest that task and motivation levels could play a very important role in explaining some of the differential effects of aging on decision preferences observed in previous studies (Löckenhoff and Carstensen 2007; Mata *et al.* 2011; Mather and Carstensen 2005; Mather and Johnson 2000). Several studies, particularly in neuroscience, have argued that top-down changes in motivation play a substantial — if not primary — role in the aging brain (Braver *et al.* 2014; Samanez-Larkin and Knutson 2015; Samanez-Larkin *et al.* 2014). Though we did not explicitly measure motivation levels, we contend that differences in engagement and motivation across tasks could explain our findings across studies. The same older individuals who made sub-optimal choices that were driven by the order in which information was presented in the risky-choice task switched to more deliberate and compensatory choices when choosing between annuities, a decision that was more relevant for them. The interplay of these task-based differences with individual differences in fluid and crystallized intelligence should be explored further in future empirical studies using larger samples.

One limitation of this study was that we focused on analysis by group rather than treating age as a continuous variable. Though the groups were selected a priori in both studies, it remains unclear if the effects represent a gradual change with age or a sudden shift at a particular age threshold. We did not have sufficient statistical power to treat age as a continuous variable in our analyses, particularly in Study 2 where we did not have the exact age information for a number of younger participants. We hope these findings can be explored in future studies using a continuous sample of participants between ages of 18 and 80.

Nonetheless, these findings have important implications for public policy and the development of interventions for decision-making. If motivation and task relevance play an important role in guiding decision strategies, it may not be prudent to overgeneralize findings from simple risky-choice tasks in the lab to the real-world decision-making. Similarly, interventions designed for certain decision environments to facilitate decision-making may not always generalize to other decision domains and environments.

Conclusions

Across two independent studies, younger adults showed a strong preference for options that maximized the overall probability of winning, but adapted their preferences to systematic changes in trial types in a complex risky-choice task involving mixed gambles. In contrast, older adults showed a strong preference for maximizing the largest gain, but did not change their preference across trial types, and were influenced by task-irrelevant factors like presentation format. Strikingly, these aging effects did not generalize to an annuity task in the second study, where older adults were less susceptible to task-irrelevant factors when choosing between annuities than younger adults. Our findings demonstrate that motivation and task relevance play an important role in guiding age-related changes in decision strategies.

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