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Who Dares, Who Errs? Disentangling Cognitive and Motivational Roots of Age Differences in Decisions Under Risk

Thorsten Pachur[1], Rui Mata[2], and Ralph Hertwig[1]
[1]Center for Adaptive Rationality, Max Planck Institute for Human Development, and [2]Center for Cognitive and Decision Sciences, Department of Psychology, University of Basel

Abstract
We separate for the first time the roles of cognitive and motivational factors in shaping age differences in decision making under risk. Younger and older adults completed gain, loss, and mixed-domain choice problems as well as measures of cognitive functioning and affect. The older adults' decision quality was lower than the younger adults' in the loss domain, and this age difference was attributable to the older adults' lower cognitive abilities. In addition, the older adults chose the more risky option more often than the younger adults in the gain and mixed domains; this difference in risk aversion was attributable to less pronounced negative affect among the older adults. Computational modeling with a hierarchical Bayesian implementation of cumulative prospect theory revealed that the older adults had higher response noise and more optimistic decision weights for gains than did the younger adults. Moreover, the older adults showed no loss aversion, a finding that supports a positivity-focus (rather than a loss-prevention) view of motivational reorientation in older age.

Keywords
aging, decisions under risk, risk attitude, affect, open data

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As life expectancy increases, the percentage of adults age 65 years and older in the industrialized world is projected to rise to 32% by 2060, from 21% in 2015 (Vaupel, 2010). A growing number of senior citizens will thus face consequential choices pertaining to their financial and medical well-being; moreover, they will play influential roles in shaping public policy. Many of these decisions will have consequences that cannot be predicted with certainty. How do older adults differ from younger adults when it comes to making decisions under risk?

One approach to examining age differences in risky decision making that is often used in psychology and economics is to ask people to choose between monetary lotteries for which relevant information about risk and reward is explicitly described (e.g., a choice between an option offering a 30% chance of winning \$500 and nothing otherwise and an option offering an 80% chance of winning \$120 and nothing otherwise). Descriptive analyses of people's risky choices have focused on two main characteristics: *decision quality* and *risk aversion*. Both are likely to be subject to age-related change (Mather et al., 2012; Tymula, Belmaker, Ruderman, Glimcher, & Levy, 2013; Weller, Levin, & Denburg, 2010). Decision quality is defined as the frequency with which the decision maker chooses the option with the higher *expected value*, defined as $\Sigma p_i x_i$, where p_i and x_i are the probability and the amount of money, respectively, associated with each possible outcome of an option. Risk aversion refers to the decision maker's distaste for the option with the higher variability in possible outcomes.

Age differences in decision quality and risk aversion are likely to have different psychological roots. The

Corresponding Author:
Thorsten Pachur, Max Planck Institute for Human Development, Center for Adaptive Rationality, Lentzeallee 94, Berlin 14195, Germany
E-mail: pachur@mpib-berlin.mpg.de

ability to identify the option with the higher expected value requires, by definition, the ability to integrate risk and reward information and might therefore rest on fluid abilities (Li, Baldassi, Johnson, & Weber, 2013; Tymula et al., 2013), which decline in older age (Hartshorne & Germine, 2015). The degree of risk aversion, by contrast, seems to be shaped more by emotional than by cognitive factors. Both the presence of positive affect and the absence of negative affect have been shown to decrease risk aversion (Chou, Lee, & Ho, 2007; Lerner & Keltner, 2001). This pattern of results is consistent with Forgas's (1995) affect infusion model, according to which positive affect focuses attention on positive aspects of an option, increasing its perceived attractiveness. Older adults tend to report both higher positive and lower negative affect than younger adults (Kunzmann, Little, & Smith, 2000; for a discussion of the underlying mechanisms, see Mather, 2016). Consequently, they may be more willing to take risks—a perhaps surprising prediction given that older adults report being less likely to engage in risky activities in numerous life domains (Josef et al., 2016).

To date, little work has clearly separated age differences in decision quality and risk aversion and identified their respective psychological origins. Several studies have found that older adults make poorer choices than younger adults, but few have examined the psychological underpinnings of this decline in decision quality (Henninger, Madden, & Huettel, 2010; Tymula et al., 2013; Weller et al., 2010). For age differences in risk aversion, the picture is even muddier. The findings of studies and meta-analyses are mixed: Older adults, compared with younger adults, have been found to be more, less, or equally willing to take risks in behavioral tasks (Best & Charness, 2015; Mata, Josef, Samanez-Larkin, & Hertwig, 2011). Various aspects of the task are likely to contribute to this heterogeneity (e.g., whether the task requires sequential learning; Mata et al., 2011), as are characteristics of the stimuli used. Specifically, most previous studies have used choice problems in which respondents choose between a risky option and a safe gain or a safe loss (Best & Charness, 2015; Mather et al., 2012; Tymula et al., 2013). Yet this approach may confound age differences in willingness to take a risk with differences in cognitive ability: Accepting a sure gain and rejecting a sure loss are cognitively less effortful than is trading off outcomes and probabilities (Burks, Carpenter, Goette, & Rustichini, 2009; Whitney, Rinehart, & Hinson, 2008). Therefore, options with sure gains might become more likely to be accepted, and options with sure losses might become more likely to be rejected, when cognitive resources decline. Studies have indeed found that people with lower cognitive ability are more likely to choose a certain (safe) gain over a risky (but higher) gain (Dohmen, Falk, Huffman, & Sunde, 2010; Henninger et al., 2010).

In the study reported in this article, we investigated age differences in risky decision making with three goals in mind. First, in order to overcome the possible confound between risk attitude and cognitive ability just mentioned, we focused on choice problems in which both options involved risk (in different degrees). Thus, we were able to study decision quality and risk attitude independently of each other. Second, we administered measures of cognitive functioning and of positive and negative affect to identify whether specific age-related patterns in decision quality and risk aversion are shaped by age-related differences in cognition, in motivation, or in both. Third, we decomposed similarities and dissimilarities in younger and older adults' risky choices using the computational modeling framework of cumulative prospect theory (CPT; Tversky & Kahneman, 1992). This approach makes it possible to identify and disentangle underlying mechanisms that are not directly discernible in people's choices, but it has rarely been harnessed to examine age differences in risky choice (but see Rutledge et al., 2016; Tymula et al., 2013).

CPT assumes that the objective monetary outcomes of a lottery are transformed into subjective values by way of a *value function*. This function is characterized by diminishing marginal utility, which is often also interpreted as outcome sensitivity, and by loss aversion (i.e., a stronger sensitivity to losses than to gains). In addition, CPT assumes a *probability weighting function* that transforms objective (cumulative) probabilities into subjective decision weights, following an inverse S-shaped curvature. The degree of curvature is taken to represent sensitivity to differences in probabilities. The elevation of the function is typically interpreted as indicating the individual's degree of optimism (Gonzalez & Wu, 1999). The thus-transformed outcomes and probabilities are then integrated multiplicatively to yield an option's overall valuation. A choice between two options is predicted by feeding the CPT valuations into a probabilistic choice rule that permits response noise to be quantified.

Several authors have discussed how CPT's value and weighting functions (whose shapes are governed by parameters that can be fitted to people's choices) may differ between younger and older adults (Hess, 2015; Mata & Hertwig, 2011). First, as a result of a stronger reliance on affect, older adults may show a more strongly curved value function (for gains and losses) than younger adults, an indication of lower outcome sensitivity (Hess, 2015). All else being equal, this would imply lower decision quality for older adults, as well as higher risk aversion in the gain domain and lower risk aversion in the loss domain. Second, as a result of a motivational reorientation involving a stronger focus on gains in older age (e.g., Mather & Carstensen, 2005), older adults' value functions for the gain and loss domains may be systematically different from younger adults'. To the extent that such motivational reorientation is reflected in an increased striving to prevent losses (Depping & Freund, 2012), the value function for losses may be even more different from the value function for gains in older adults than in younger adults, which would imply higher loss aversion; note that this also means that older adults would be more risk averse in the loss domain than younger adults. Alternatively, if motivational reorientation unfolds as a positivity bias (Mather & Carstensen, 2005), then older adults would show higher sensitivity to gains and lower sensitivity to losses compared with younger adults, which would imply lower loss aversion for older adults.

Regarding probability weighting, it has been suggested that—because of a stronger reliance on affect (Hess, 2015), reduced numerical abilities (Peters, Hess, Västfjäll, & Auman, 2007), or both—older adults show a more strongly inverse S-shaped weighting function than younger adults do, and consequently exhibit lower decision quality (all else being equal). Further, older adults' greater reliance on emotions could bring about a more elevated weighting function (Hess, 2015; Rottenstreich & Shu, 2004), which would, in turn, cause lower risk aversion for gains and higher risk aversion for losses. In the study that follows, we tested, to our knowledge for the first time, these partially competing hypotheses of how age differences in choice map onto the conceptual framework of CPT.

Method

Participants

We recruited 60 younger adults (46 female, 14 male) ages 18 to 30 years (M = 23.6, SD = 3.1) and 62 healthy older adults (31 female, 29 male, 2 who did not report their gender) ages 63 to 88 years (M = 71.3, SD = 6.4), both drawn from the subject-pool database maintained by the Department of Psychology at the University of Basel. Prior to conducting the study, we targeted a sample size of 60 for each age group, somewhat higher than in a related study by Mather et al. (2012). Two additional participants were recruited to the group of older adults by mistake (see Table 1 for additional sociodemographic information on the two groups). Participants received a fixed fee of 25 Swiss francs (CHF; ~U.S.$27.40), augmented by a performance-dependent bonus (see the next section).

Materials and procedure

Participants were tested individually. They first read instructions detailing the risky choice task, procedure, and payoffs. Then they completed two practice trials in which they familiarized themselves with the computer. They were encouraged to be thorough and careful in completing the task and were reminded that their payoff would depend on one of their choices (randomly

Table 1. Sociodemographic Characteristics of the Participants in the Two Age Groups

	Age group	
Characteristic	Younger	Older
n	60	62
Sex (female/male)	46/14	31/29
Age (years)	M = 23.6, SD = 3.1	M = 71.3, SD = 6.4
Education		
Elementary school	3	30
High school	33	2
University	24	28
Assets		
< 500 CHF	5	1
500–40,000 CHF	45	1
40,000–80,000 CHF	3	4
> 80,000 CHF	3	36
Debts		
< 500 CHF	42	29
500–40,000 CHF	6	6
> 40,000 CHF	0	11

Note: Except as noted, the numbers in the table indicate the number of participants in each category. For some variables, the numbers do not add up to the total for one or both of the age groups because some participants did not provide a response. CHF = Swiss francs.

Table 2. Mean Scores of Younger and Older Adults on the Cognitive and Affective Measures, and Comparison Between the Two Age Groups

	Age group		Group comparison		
Variable	Younger	Older	t	p	d
Numeracy (0–10)	8.7 (1.3)	7.3 (2.1)	$t(117) = 4.56$	< .001	0.83
Fluid abilities (0–93)	59.8 (10.2)	39.4 (10.1)	$t(117) = 10.95$	< .001	2.00
Crystallized abilities (0–37)	31.4 (2.7)	33.6 (1.6)	$t(118) = -5.41$	< .001	−0.99
Positive affect (1–7)	4.8 (1.1)	5.4 (0.9)	$t(118) = -3.5$	.001	−0.64
Negative affect (1–7)	2.2 (1.1)	1.5 (0.6)	$t(118) = 4.2$	< .001	0.85

Note: Numeracy was tested with Lipkus, Samsa, and Rimer's (2001) general numeracy scale, fluid abilities were tested with Wechsler's (1981) Digit-Symbol Substitution Test, crystallized abilities were tested with Lehrl's (1977) Spot-a-Word vocabulary test, and positive and negative affect were tested with the short version of Grühn, Kotter-Grühn, and Röcke's (2010) Positive Affect Negative Affect Schedule–Extended. For the mean scores of the age groups, standard deviations are given in parentheses.

selected), with a positive outcome being added to and a negative outcome being subtracted from their bonus. Participants then completed 105 sequentially presented and randomly ordered choice problems. Each problem consisted of a pair of two-outcome monetary lotteries, and participants indicated which lottery they preferred. The problems were taken from a variety of sources (see the Supplemental Material available online for a full list) and included (a) 75 randomly constructed problems in the gain, loss, and mixed domains (25 problems in each domain; for details of the construction principle, see Rieskamp, 2008), (b) 8 problems specifically designed to measure loss aversion and 10 problems specifically designed to measure risk aversion, and (c) 12 problems designed to study probability weighting of rare events (6 problems in the gain domain and 6 problems in the loss domain). Our set of problems largely overlapped with Glöckner and Pachur's (2012) set, which has been shown to render very accurate estimates of CPT parameters (Broomell & Bhatia, 2014). Across all problems, which lottery option in a pair was more risky (larger coefficient of variation; see the Risk Aversion section) was only moderately correlated with which option was more attractive (greater expected value), $r_\varphi = .23$, $p = .019$. Additional comparisons of the problems in the gain, loss, and mixed domains are reported in the Supplemental Material.

After participants had completed the risky choice task, their overall payoff was determined by drawing 1 of the 105 problems randomly and playing out the chosen option. The outcome was paid out with a conversion rate of 10:1. Finally, participants provided demographic information (gender, educational attainment, financial assets) and completed measures of cognitive abilities and affect.

As a measure of fluid cognitive abilities, we used Wechsler's (1981) Digit-Symbol Substitution Test. As a measure of crystallized abilities, we used Lehrl's (1977) Spot-a-Word vocabulary test. Participants also completed a general numeracy scale (Lipkus, Samsa, & Rimer, 2001), measuring their understanding of stochastic processes (e.g., the concept of a random coin toss) and their ability to perform elementary calculations with percentages. Numeracy should recruit both fluid and crystallized abilities, but it has also been shown to be separable from them (e.g., Dieckmann et al., 2015). As expected (Hartshorne & Germine, 2015; Park et al., 2002), younger adults scored higher than older adults on fluid abilities and numeracy, whereas older adults scored higher than younger adults on crystallized abilities (see Table 2).

Finally, participants responded to a short version of the Positive Affect Negative Affect Schedule–Extended (PANAS-X; Grühn, Kotter-Grühn, & Röcke, 2010). This version consists of four items measuring positive affect (enthusiastic, excited, happy, content) and four items measuring negative affect (nervous, upset, sad, frustrated). The score for each scale is the mean rating—from 1 (*very slightly or not at all*) to 7 (*extremely*)—across the four items. As expected, older adults scored higher on positive affect and lower on negative affect than younger adults did (see Table 2).

Results

The choice proportions for each of the choice problems, aggregated separately across younger and older adults, are reported in the Supplemental Material. In this section, we first examine age differences in decision quality and risk aversion and then analyze how participants' choices related to measures of cognitive ability and affect. Finally, we use computational modeling with CPT to decompose choices and age differences in choices into outcome sensitivity, loss aversion, probability weighting, and response noise.

Decision quality

To measure decision quality, we determined each participant's tendency to choose the option with the higher

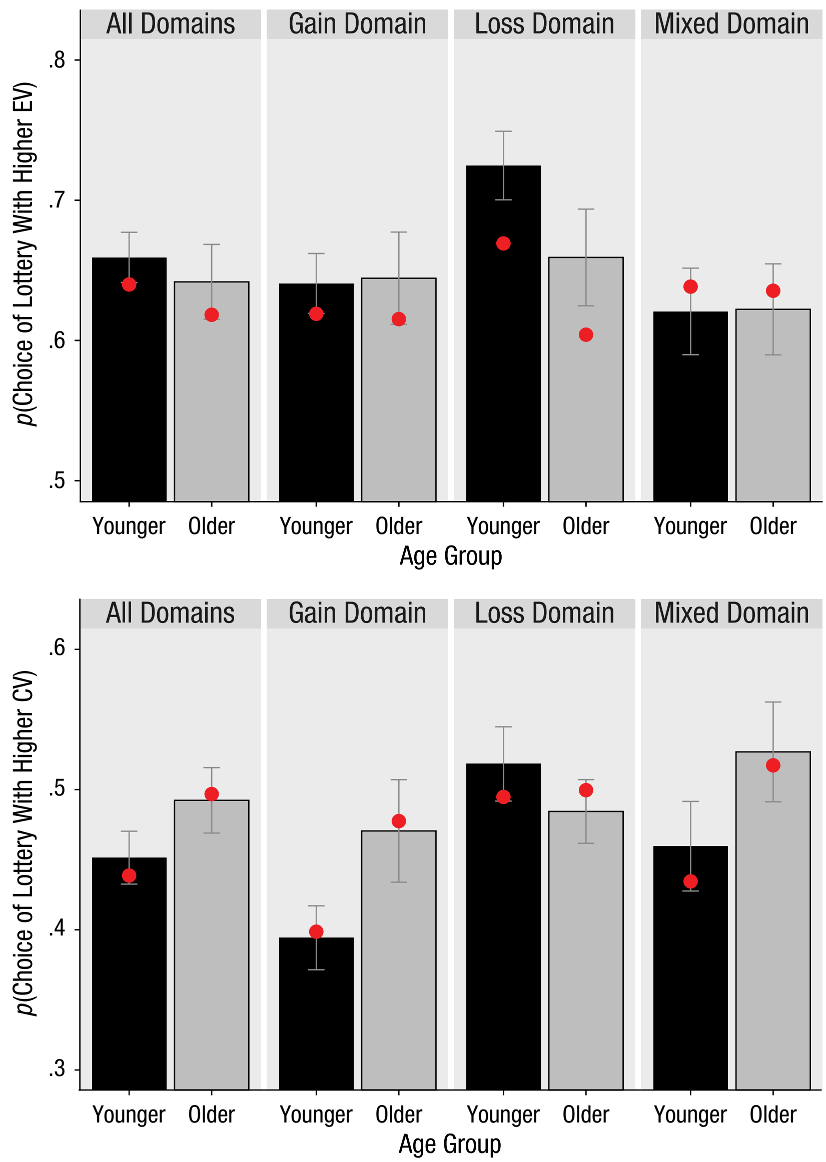

Fig. 1. Average proportion of choices of the lottery with the higher expected value (EV; decision quality, upper panel) and the higher coefficient of variation (CV; risk aversion, lower panel), separately for the two age groups and each domain, as well as aggregated across the three domains. Error bars indicate 95% confidence intervals. The red dots show the average (across participants) choice proportions derived from cumulative prospect theory using the mean (across participants) estimated parameters.

expected value. The upper panel of Figure 1 shows the average (across participants) proportion of choices of the option with the higher expected value, separately for the younger and older participants and separately for each domain, as well as aggregated across the three domains. Note that because the characteristics of the choice problems were not identical across the three domains (see the Supplemental Material), one would not necessarily expect the proportion of choices of the option with higher expected value to be the same in each domain.

In order to examine differences in decision quality between younger and older adults, we conducted a mixed-effects logistic regression analysis, predicting whether participants chose the option with the higher expected value in each problem (Bates, Maechler, Bolker, & Walker, 2015). Participant and choice problem were included as random intercepts, and age group and domain as well as their interaction were included as fixed effects. To control for effects of risk aversion, we included whether a participant chose the option with the higher coefficient of variation (see the Risk Aversion section) as a fixed-effect covariate. Finally, we entered gender, assets, and education as additional fixed-effect covariates.

The results showed an interaction between age group and domain. Specifically, in the loss domain—but not in the gain or mixed domain—older adults were less likely than younger adults to select the option with the higher expected value. There was a significant difference in the size of the age effect between the loss and gain domains (b = −0.230, 95% confidence interval, CI = [−0.434, −0.022]; odds ratio = 0.796, 95% CI = [0.648, 0.978]), but the age effect did not differ between the gain and mixed domains (b = −0.020, 95% CI = [−0.220, 0.179]; odds ratio = 0.980, 95% CI = [0.803, 1.196]). Although Figure 1 suggests that younger adults' decision quality was higher in the loss domain than in the other two domains, the mixed-effects analysis (controlling for risk aversion) did not corroborate this impression. Specifically, younger adults' decision quality was not significantly lower in either the gain domain (b = −0.212, 95% CI = [−0.855, 0.432]; odds ratio = 0.809, 95% CI = [0.425, 1.54]) or the mixed domain (b = −0.469, 95% CI = [−1.143, 0.206]; odds ratio = 0.626, 95% CI = [0.319, 1.229]) than in the loss domain. There was no evidence that the relatively large number of choice problems that participants had to complete affected their decision quality or affected the younger and older adults differentially (see analysis in the Supplemental Material).

Risk aversion

To quantify individual risk aversion, we determined each participant's tendency to choose the option with the higher *coefficient of variation*. The coefficient of variation is defined as the standard deviation of the lottery[1] divided by the absolute magnitude of its expected value. It thus expresses how much relative risk a person has to accept to obtain 1 unit of return from the option; a higher value indicates higher risk, and the coefficient of variation is therefore often used as a measure of the risk associated with an option (see Weber, Shafir, & Blais, 2004, for a discussion of the advantages of using this relative-variability measure rather than the variance of the outcomes). The lower panel in Figure 1 shows the average (across participants) proportion of problems for which the younger and older adults' chose the riskier option, separately for each domain and across all three domains. A lower proportion indicates higher risk aversion. To examine age differences, we conducted a mixed-effects logistic regression analysis similar to the one for decision quality, with participant and choice problem as random intercepts and age group and domain as well as their interaction as fixed effects. Further, to control for the effect of decision quality, we included whether a participant chose the option with the higher expected value as a fixed-effect covariate. Finally, we entered gender, education, and assets as additional fixed-effect covariates.

The analysis revealed a significant interaction between age group and domain. Older adults showed less risk aversion than younger adults (i.e., they were more likely to choose the riskier option) in the gain domain (relative to the loss domain; b = 0.513, 95% CI = [0.308, 0.718]; odds ratio = 1.671, 95% CI = [1.361, 2.050]) and in the mixed domain (relative to the loss domain; b = 0.420, 95% CI = [0.209, 0.632]; odds ratio = 1.523, 95% CI = [1.232, 1.881]).

To summarize, we observed two independent differences between younger and older adults' risky choices: First, older adults' decision quality in the loss domain was lower than younger adults', and, second, older adults were less risk averse than younger adults in the gain and mixed domains. Note that these results emerged despite the fact that educational attainment (which we controlled for in the analyses) differed somewhat between the age groups (see Table 1). Figure S1 in the Supplemental Material shows the age differences in decision quality and risk aversion specifically among the younger and older adults with a university degree.

Are the age differences in choice associated with cognitive ability or affect?

To test the extent to which the older adults' poorer decision quality and lower risk aversion were associated with concurrent age differences in cognitive ability or affect, we conducted a series of mixed-effects logistic regression analyses in which we examined the effect of including the measures of numeracy, fluid abilities, crystallized abilities, and positive and negative affect as additional covariates. Because age differences in risky choice differed across the domains, these analyses were conducted separately for the gain, loss, and mixed domains. Furthermore, we calculated three separate regression models for decision quality, for risk aversion, and for each domain. In the first model, only age group was included as a predictor (in addition to risk aversion and decision quality, respectively, when they served as covariates). In the second model, the sociodemographic variables (i.e., gender, education, and assets) were added as predictors. The third model also included the measures of cognitive ability and affect.

Tables 3 and 4 show the regression coefficients and odds ratios, respectively, obtained for each predictor in each model. Age differences in decision quality disappeared once we controlled for cognitive abilities and affect (Model 2 vs. Model 3). Specifically, the positive association of decision quality with numeracy and fluid

Table 3. Regression Coefficients From the Mixed-Effects Logistic Regression of Participants' Responses in the Risky Choice Task

Outcome and predictor	Gain domain			Loss domain			Mixed domain		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Decision quality									
Age group (older)	−0.108 [−0.292, 0.076]	**−0.244 [−0.445, −0.043]**	−0.044 [−0.340, 0.252]	**−0.337 [−0.553, −0.122]**	**−0.430 [−0.672, −0.188]**	−0.099 [−0.452, 0.254]	−0.139 [−0.340, 0.062]	−0.209 [−0.439, 0.022]	−0.048 [−0.396, 0.300]
Gender (male)	—	**0.251 [0.057, 0.444]**	0.157 [−0.039, 0.353]	—	0.161 [−0.071, 0.393]	0.097 [−0.136, 0.330]	—	0.054 [−0.166, 0.274]	0.042 [−0.188, 0.271]
Education	—	0.012 [−0.087, 0.110]	0.017 [−0.077, 0.111]	—	−0.028 [−0.148, 0.092]	−0.037 [−0.150, 0.076]	—	0.007 [−0.106, 0.120]	0.004 [−0.106, 0.115]
Assets	—	0.014 [−0.005, 0.032]	0.006 [−0.012, 0.024]	—	0.016 [−0.006, 0.038]	0.012 [−0.010, 0.033]	—	0.010 [−0.011, 0.031]	0.006 [−0.015, 0.027]
Numeracy	—	—	**0.086 [0.032, 0.140]**	—	—	**0.088 [0.024, 0.152]**	—	—	0.035 [−0.029, 0.099]
Fluid abilities	—	—	0.004 [−0.005, 0.013]	—	—	**0.012 [0.001, 0.022]**	—	—	0.009 [−0.001, 0.020]
Crystallized abilities	—	—	0.011 [−0.029, 0.050]	—	—	0.022 [−0.026, 0.069]	—	—	0.046 [−0.001, 0.092]
Positive affect	—	—	0.035 [−0.069, 0.139]	—	—	−0.040 [−0.165, 0.085]	—	—	−0.038 [−0.160, 0.085]
Negative affect	—	—	−0.003 [−0.119, 0.113]	—	—	−0.089 [−0.227, 0.049]	—	—	−0.056 [−0.192, 0.080]
Intercept	−0.051 [−0.452, 0.350]	−0.207 [−0.698, 0.284]	−1.658 [−3.187, −0.129]	1.068 [0.780, 1.356]	1.034 [0.583, 1.485]	−0.676 [−2.459, 1.107]	−0.323 [−0.663, 0.017]	−0.404 [−0.876, 0.069]	−2.387 [−4.159, −0.616]
CV choice	2.009 [1.846, 2.172]	2.006 [1.842, 2.170]	2.024 [1.859, 2.190]	−0.049 [−0.208, 0.110]	−0.055 [−0.215, 0.106]	−0.051 [−0.212, 0.110]	2.153 [1.978, 2.329]	2.157 [1.980, 2.333]	2.144 [1.966, 2.322]
Risk aversion									
Age group (older)	**0.425 [0.202, 0.647]**	**0.457 [0.200, 0.713]**	0.148 [−0.243, 0.539]	**−0.178 [−0.354, −0.002]**	−0.124 [−0.325, 0.077]	−0.055 [−0.372, 0.263]	**0.349 [0.144, 0.555]**	**0.392 [0.153, 0.630]**	**0.372 [0.007, 0.738]**
Gender (male)	—	−0.019 [−0.264, 0.226]	−0.014 [−0.271, 0.244]	—	−0.018 [−0.210, 0.174]	−0.011 [−0.221, 0.198]	—	−0.043 [−0.270, 0.184]	−0.030 [−0.270, 0.211]
Education	—	−0.022 [−0.148, 0.105]	−0.007 [−0.132, 0.118]	—	−0.066 [−0.165, 0.032]	−0.071 [−0.173, 0.030]	—	−0.040 [−0.157, 0.077]	−0.029 [−0.146, 0.087]
Assets	—	−0.001 [−0.024, 0.022]	0.004 [−0.020, 0.027]	—	0.000 [−0.018, 0.019]	0.000 [−0.019, 0.020]	—	−0.001 [−0.023, 0.020]	−0.003 [−0.025, 0.020]
Numeracy	—	—	−0.041 [−0.113, 0.031]	—	—	0.005 [−0.053, 0.063]	—	—	−0.032 [−0.099, 0.035]
Fluid abilities	—	—	−0.008 [−0.020, 0.003]	—	—	0.003 [−0.006, 0.013]	—	—	0.004 [−0.007, 0.015]
Crystallized abilities	—	—	−0.009 [−0.062, 0.043]	—	—	0.005 [−0.037, 0.048]	—	—	−0.014 [−0.063, 0.035]
Positive affect	—	—	−0.069 [−0.207, 0.068]	—	—	−0.004 [−0.116, 0.108]	—	—	0.107 [−0.021, 0.236]
Negative affect	—	—	**−0.177 [−0.331, −0.024]**	—	—	−0.005 [−0.129, 0.120]	—	—	−0.025 [−0.168, 0.118]
Intercept	−1.864 [−2.333, −1.395]	−1.794 [−2.388, −1.200]	0.009 [−2.007, 2.025]	0.128 [−0.287, 0.543]	0.324 [−0.180, 0.827]	−0.051 [−1.698, 1.596]	−1.540 [−1.955, −1.125]	−1.412 [−1.946, −0.878]	−1.409 [−3.284, 0.466]
EV choice	1.982 [1.818, 2.146]	1.981 [1.816, 2.147]	1.995 [1.827, 2.162]	−0.036 [−0.195, 0.123]	−0.043 [−0.203, 0.118]	−0.043 [−0.205, 0.119]	2.158 [1.982, 2.334]	2.161 [1.984, 2.338]	2.150 [1.972, 2.329]

Note: For the analysis of decision quality, the dependent variable was equal to 1 if the participant chose the lottery with the higher expected value (EV) and 0 otherwise. For the analysis of risk aversion, the dependent variable was equal to 0 if the participant chose the lottery with the lower coefficient of variation (CV) and 1 otherwise. Values in brackets are bootstrapped 95% confidence intervals. Results in boldface indicate significant predictors.

Table 4. Odds Ratios From the Mixed-Effects Logistic Regression of Participants' Responses in the Risky Choice Task

Outcome and predictor	Gain domain			Loss domain			Mixed domain		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Decision quality									
Age group (older)	0.898 [0.747, 1.079]	**0.783 [0.641, 0.958]**	0.957 [0.712, 1.286]	**0.714 [0.575, 0.885]**	**0.650 [0.511, 0.828]**	0.906 [0.636, 1.289]	0.870 [0.712, 1.064]	0.812 [0.644, 1.022]	0.953 [0.673, 1.350]
Gender (male)	—	**1.285 [1.059, 1.559]**	1.170 [0.962, 1.423]	—	1.175 [0.932, 1.482]	1.102 [0.873, 1.391]	—	1.055 [0.847, 1.315]	1.043 [0.829, 1.312]
Education	—	1.012 [0.916, 1.117]	1.017 [0.925, 1.117]	—	0.972 [0.863, 1.096]	0.964 [0.861, 1.079]	—	1.007 [0.899, 1.128]	1.004 [0.899, 1.122]
Assets	—	1.014 [0.996, 1.032]	1.006 [0.988, 1.024]	—	1.016 [0.994, 1.039]	1.012 [0.990, 1.033]	—	1.010 [0.989, 1.031]	1.006 [0.985, 1.028]
Numeracy	—	—	**1.089 [1.032, 1.150]**	—	—	**1.092 [1.025, 1.164]**	—	—	1.036 [0.972, 1.104]
Fluid abilities	—	—	1.004 [0.995, 1.013]	—	—	**1.012 [1.001, 1.022]**	—	—	1.010 [0.999, 1.020]
Crystallized abilities	—	—	1.011 [0.972, 1.052]	—	—	1.022 [0.975, 1.071]	—	—	1.047 [0.999, 1.097]
Positive affect	—	—	1.035 [0.933, 1.149]	—	—	0.961 [0.848, 1.089]	—	—	0.963 [0.852, 1.089]
Negative affect	—	—	0.997 [0.888, 1.119]	—	—	0.915 [0.797, 1.051]	—	—	0.945 [0.825, 1.083]
Intercept	0.950 [0.636, 1.419]	0.813 [0.497, 1.328]	0.191 [0.041, 0.879]	2.911 [2.182, 3.882]	2.812 [1.791, 4.415]	0.508 [0.085, 3.024]	0.724 [0.515, 1.017]	0.668 [0.416, 1.071]	0.092 [0.016, 0.540]
CV choice	7.455 [6.332, 8.777]	7.430 [6.306, 8.754]	7.571 [6.416, 8.933]	0.952 [0.812, 1.117]	0.947 [0.807, 1.111]	0.950 [0.809, 1.116]	8.612 [7.226, 10.265]	8.642 [7.241, 10.313]	8.536 [7.145, 10.198]
Risk aversion									
Age group (older)	**1.529 [1.224, 1.909]**	**1.579 [1.221, 2.041]**	1.159 [0.784, 1.714]	**0.837 [0.702, 0.998]**	0.883 [0.722, 1.080]	0.947 [0.689, 1.301]	**1.418 [1.155, 1.741]**	**1.480 [1.166, 1.878]**	**1.451 [1.007, 2.091]**
Gender (male)	—	0.981 [0.768, 1.253]	0.986 [0.762, 1.276]	—	0.982 [0.811, 1.190]	0.989 [0.802, 1.219]	—	0.958 [0.764, 1.202]	0.971 [0.763, 1.234]
Education	—	0.979 [0.862, 1.110]	0.993 [0.877, 1.125]	—	0.936 [0.848, 1.033]	0.931 [0.841, 1.030]	—	0.960 [0.854, 1.080]	0.971 [0.864, 1.091]
Assets	—	0.999 [0.976, 1.022]	1.004 [0.980, 1.028]	—	1.000 [0.982, 1.019]	1.000 [0.981, 1.020]	—	0.999 [0.977, 1.021]	0.997 [0.975, 1.020]
Numeracy	—	—	0.960 [0.894, 1.031]	—	—	1.005 [0.948, 1.065]	—	—	0.968 [0.905, 1.036]
Fluid abilities	—	—	0.992 [0.980, 1.003]	—	—	1.003 [0.994, 1.013]	—	—	1.004 [0.993, 1.015]
Crystallized abilities	—	—	0.991 [0.940, 1.044]	—	—	1.005 [0.963, 1.049]	—	—	0.986 [0.938, 1.035]
Positive affect	—	—	0.933 [0.813, 1.070]	—	—	0.996 [0.891, 1.114]	—	—	1.113 [0.979, 1.266]
Negative affect	—	—	**0.837 [0.718, 0.976]**	—	—	0.995 [0.879, 1.127]	—	—	0.975 [0.845, 1.125]
Intercept	0.155 [0.097, 0.248]	0.166 [0.092, 0.301]	1.009 [0.134, 7.573]	1.137 [0.751, 1.722]	1.382 [0.835, 2.287]	0.950 [0.183, 4.932]	0.214 [0.142, 0.325]	0.244 [0.143, 0.416]	0.244 [0.037, 1.594]
EV choice	7.256 [6.157, 8.550]	7.252 [6.146, 8.556]	7.349 [6.218, 8.687]	0.965 [0.823, 1.131]	0.958 [0.816, 1.125]	0.958 [0.815, 1.127]	8.653 [7.259, 10.315]	8.683 [7.275, 10.365]	8.586 [7.184, 10.263]

Note: For the analysis of decision quality, the dependent variable was equal to 1 if the participant chose the lottery with the higher expected value (EV) and 0 otherwise. For the analysis of risk aversion, the dependent variable was equal to 0 if the participant chose the lottery with the lower coefficient of variation (CV) and 1 otherwise. Values in brackets are bootstrapped 95% confidence intervals. Results in boldface indicate significant predictors.

abilities (lower in older adults; Table 2) indicated that higher levels of numeracy and fluid intelligence were linked with more frequent choices of the option with the higher expected value. By contrast, the age differences in risk aversion, which disappeared in the gain domain once we controlled for cognitive abilities and affect, were associated with the amount of negative affect (lower in older adults; Table 2). Specifically, the lower the level of negative affect, the more frequently the riskier option was chosen. The age difference in risk aversion in the mixed domain did not disappear once we controlled for cognitive abilities and affect.

The relationships, first, between decision quality and fluid abilities and, second, between risk aversion and negative affect are also illustrated in Figure 2, which presents decision quality and risk aversion for each age group

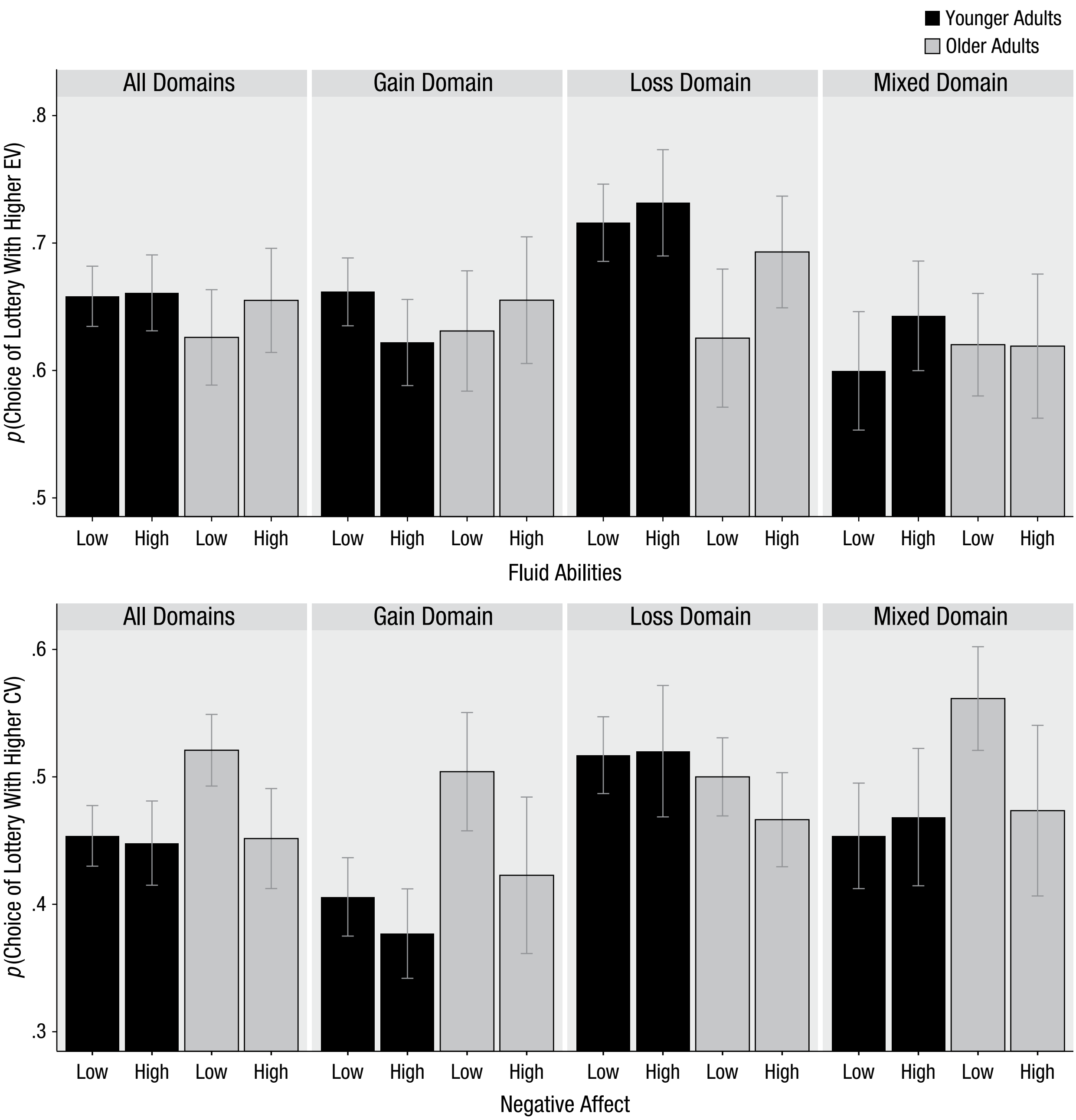

Fig. 2. Association of age differences in risky choice with fluid abilities and negative affect. For each domain, and aggregated across the three domains, the average proportion of choices of the option with the higher expected value (EV; decision quality, upper panel) and the higher coefficient of variation (CV; risk aversion, lower panel) is graphed separately for subgroups within each age group. For decision quality, the subgroups were defined by whether participants' fluid intelligence scores were lower than (or equal to) or higher than the median for their age group, and for risk aversion, the subgroups were defined by whether participants' negative-affect scores were lower than (or equal to) or higher than the median for their age group. Error bars indicate 95% confidence intervals.

plotted separately for participants with high versus low fluid intelligence and high versus low negative affect, respectively. The figure shows that the decision quality of high-functioning older adults in the loss domain approached that of younger adults; similarly, older adults with high levels of negative affect showed the same level of risk aversion in the gain and mixed domains as younger adults did.

Taken together, these results suggest that the age differences in decision quality and risk aversion in risky choices have distinct psychological roots, with older adults' lower decision quality being linked to their lower cognitive ability, and their lower risk aversion being linked to their lower levels of negative affect.

Computational modeling

Next, we used CPT to decompose the younger and older adults' choices into various psychological constructs:

- Outcome sensitivity is captured by parameter α. Lower values indicate lower sensitivity to differences in outcomes.
- Loss aversion is captured by parameter λ. Higher values (> 1) indicate a stronger overweighting of losses relative to gains.
- Probability sensitivity is captured by parameter γ. Lower values indicate lower sensitivity to differences in probabilities.
- Elevation is captured by parameter δ. Higher values indicate higher optimism for gain probabilities and higher pessimism for loss probabilities.
- Response noise is captured by parameter θ. Lower values indicate less systematic responses.

The modeling analysis allowed us to disentangle the influence of specific psychological mechanisms on the observed age differences in risky choice and to test the several hypotheses (outlined earlier) regarding how potential age differences in risky choice map onto CPT's value and weighting functions. We estimated the CPT parameters for each participant, using a hierarchical Bayesian approach (e.g., Scheibehenne & Pachur, 2015). In Bayesian parameter estimation, parameter estimates are initially represented in terms of prior distributions and then updated into posterior distributions based on the observed data. In the hierarchical approach, we assumed separate group-level distributions for the younger and older adults. A detailed formal description of CPT and its parameters, as well as further information about the Bayesian parameter estimation, can be found in the Supplemental Material.

The red dots in Figure 1 show the average (across participants) decision quality and risk aversion derived from CPT using the mean of each participant's posterior distribution of the parameter estimates. CPT's estimated parameters capture the main pattern of the age differences in risky choice rather well (further analyses of CPT's model fit, including a comparison with expected-utility theory, are provided in the Supplemental Material).

How did the observed choices translate into age differences in the value and weighting functions? Is there support for any of the proposed hypotheses? Figure 3 shows, separately for the younger and older adults, the individual value and weighting functions based on the estimated parameters for each participant, as well as the functions based on the group-level means. Table 5 reports the group-level means and 95% highest density intervals (HDIs, which reflect the uncertainty in the estimates) for each parameter, as well as for the posterior distributions of the differences between the age groups. We obtained credible age differences (indicated by 95% HDIs that did not include zero) on three parameters. First, older adults had a lower loss aversion parameter, λ, than younger adults. In fact, whereas younger adults showed at least some degree of loss aversion (i.e., $\lambda > 1$), older adults' λ parameter did not differ from 1, which indicates the absence of loss aversion. This pattern is inconsistent with a motivational reorientation in older age toward prevention of losses; instead, it is consistent with a motivational reorientation toward a positivity bias, which implies reduced loss aversion in older adults (Mather & Carstensen, 2005). Note, however, that despite these age differences on the λ parameter, younger adults' degree of loss aversion was also small (see also Yechiam & Hochman, 2013). Second, the elevation of the probability weighting function for gains was higher for older adults than for younger adults (as predicted by Hess, 2015). This suggests that older adults are more optimistic about the possibility of a gain. Third, older adults showed higher response noise (i.e., a smaller θ) than younger adults. Overall, there was no evidence of older adults having lower outcome sensitivity or lower probability sensitivity than younger adults.

In order to see how individual differences in CPT parameters were related to participants' choices, we regressed decision quality and risk aversion (using mixed-effects modeling as in the previous analyses) on the individual parameter estimates (across both age groups). As Table 6 shows, higher decision quality was linked with higher outcome sensitivity (i.e., higher α), higher probability sensitivity (i.e., higher γ), and lower response noise (i.e., higher θ). As there were no age differences in α or γ (Table 5), this finding suggests that the older participants' lower decision quality in the loss domain was driven mainly by their higher response noise (i.e., lower θ parameter). Risk aversion was linked to the elevation of the probability weighting function; higher elevation for gains (δ^+; i.e., more optimism) was associated with less risk aversion (i.e., more frequent choices of the option with the higher coefficient of variation), and higher elevation for losses (δ^-; i.e., more pessimism) was associated with more risk aversion. Thus, the older participants' higher elevation for gains (Fig. 3 and Table 5) might have driven their less pronounced risk aversion in the gain domain.

The findings in Table 6 also suggest why the older adults' decision quality was poorer than the younger adults' only in the loss domain. In addition to the effect of response noise on decision quality, there were trends of a positive effect of elevation for gains and a positive effect of loss aversion. Therefore, whereas the older adults' higher response noise and lower loss aversion both decreased their decision quality in the loss domain, their higher elevation in the gain domain seems to have compensated for the negative effect of their higher response noise. Finally, Table 7 shows how the model parameters were linked to the measures of cognitive ability and affect. Most important, loss aversion was negatively associated with crystallized intelligence, the

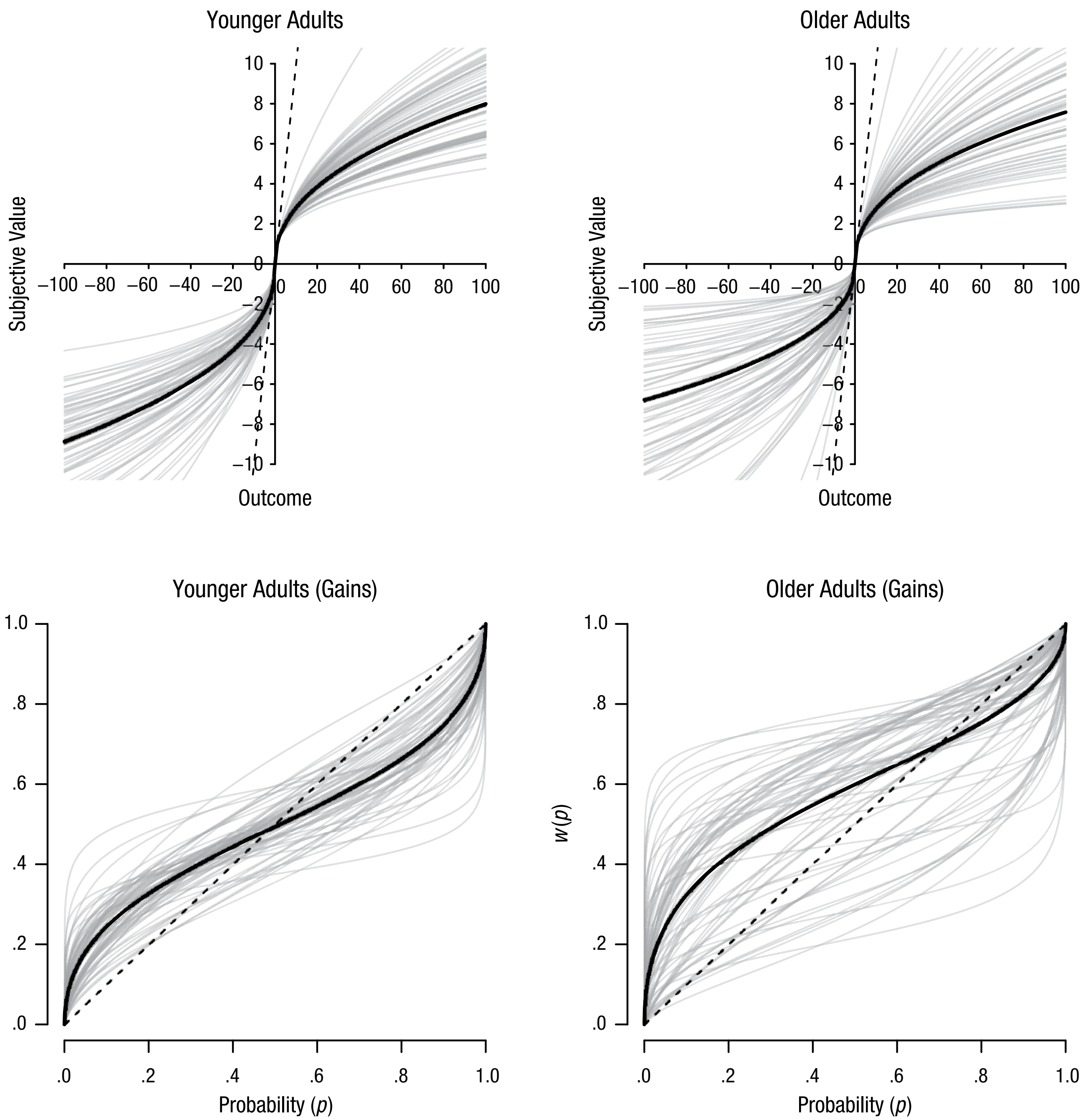

Fig. 3. *(continued on next page)*

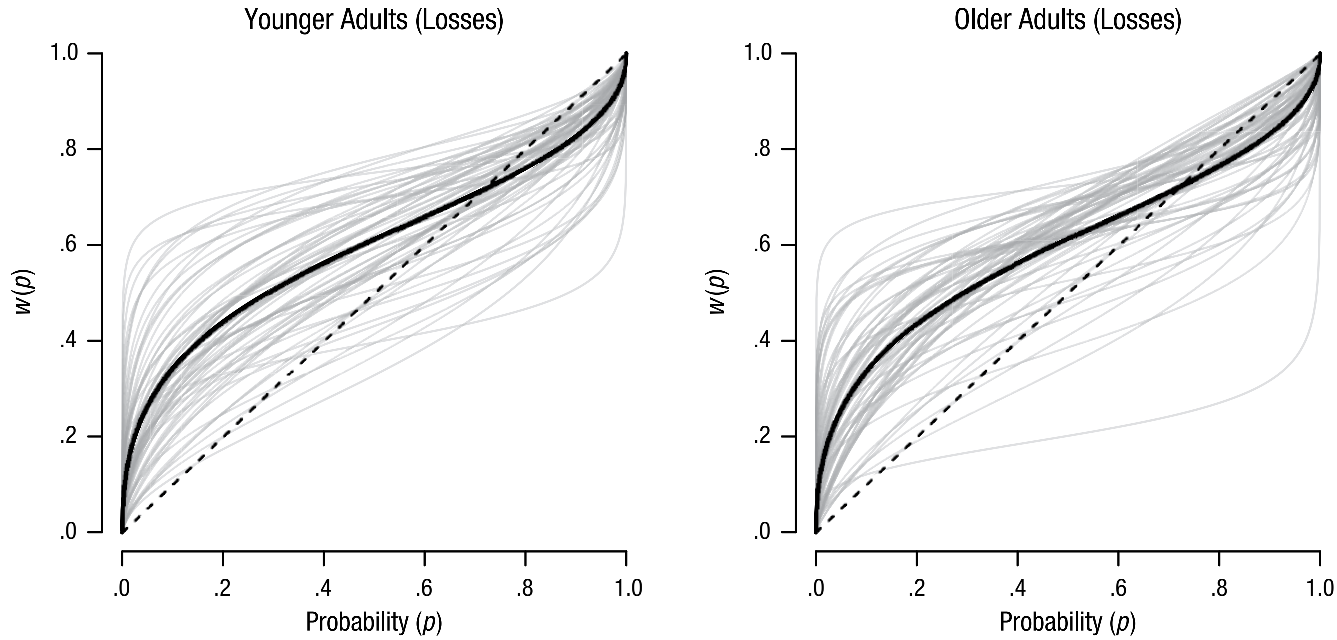

Fig. 3. Cumulative prospect theory's value function (top row) and weighting functions for gains (middle row) and losses (bottom row), estimated using each participant's choices in the 105 problems, separately for the younger (left column) and older (right column) adults. The value function shows how a lottery's outcome (*x*-axis) maps onto subjective value (*y*-axis). The weighting function shows how a probability (*x*-axis) maps onto a subjective decision weight (*y*-axis). In each graph, the gray lines are the functions for individual participants, the black line is the function based on the group-level mean, and the dotted line is the identity line. The variable $w(p)$ is the transformed objective probability, p.

elevation parameter for gains was negatively associated with negative affect and fluid intelligence, and more noise (i.e., a lower noise parameter) was associated with lower fluid intelligence and numeracy, as well as higher positive affect.

Discussion

As have previous investigations (Henninger et al., 2010; Li et al., 2013; Tymula et al., 2013), we found that older participants' decision quality was poorer than younger adults'. However, this decline was restricted to the loss domain. Independently of the age difference in decision quality, older adults' choices were less risk averse in the gain and mixed domains. We also established that age differences in decision quality and risk aversion have different psychological roots: Older adults' poorer decision quality was associated with their lower levels of fluid intelligence and numeracy; their lower risk aversion (in the gain domain), in contrast, was associated with their lower levels of negative affect. Finally, mapping participants' choices onto the influential formal framework of CPT, we found that older adults, relative to younger adults, had more optimistic decision weights for gains and higher response noise. In addition, older adults exhibited no loss aversion, whereas younger adults showed a low level of loss aversion.

Table 5. Group-Level Means From the Bayesian Hierarchical Estimation of the Cumulative Prospect Theory Parameters, Separately for the Younger and Older Adults and the Posterior Distribution for the Difference Between the Age Groups

	Parameter					
Age group	Outcome sensitivity (α)	Loss aversion (λ)	Probability sensitivity (γ)	Elevation, gains (δ^{+})	Elevation, losses (δ^{-})	Response noise (θ)
Younger	0.45 [0.41, 0.49]	1.11 [1.00, 1.22]	0.50 [0.45, 0.57]	0.98 [0.86, 1.10]	1.58 [1.27, 1.94]	1.50 [1.19, 1.86]
Older	0.44 [0.39, 0.49]	0.89 [0.75, 1.05]	0.52 [0.42, 0.63]	1.49 [1.16, 1.89]	1.58 [1.19, 2.13]	0.89 [0.67, 1.13]
Difference (older – younger)	–0.01 [–0.08, 0.05]	**–0.22 [–0.40, –0.03]**	0.02 [–0.10, 0.14]	**0.52 [0.16, 0.93]**	0.01 [–0.54, 0.63]	**–0.62 [–1.04, –0.23]**

Note: Values in brackets are 95% highest density intervals. Results in boldface indicate credible differences between the age groups.

Table 6. Regression Coefficients and Odds Ratios From the Mixed-Effects Logistic Regression Predicting Decision Quality and Risk Aversion From the Individually Estimated Cumulative Prospect Theory Parameters

Outcome and predictor	Regression coefficient	Odds ratio
Decision quality		
Outcome sensitivity (α)	**3.610 [2.978, 4.243]**	**36.982 [19.654, 69.585]**
Loss aversion (λ)	0.101 [−0.056, 0.257]	1.106 [0.945, 1.293]
Probability sensitivity (γ)	**0.764 [0.486, 1.041]**	**2.147 [1.626, 2.833]**
Elevation, gains (δ^+)	0.057 [−0.016, 0.130]	1.059 [0.984, 1.139]
Elevation, losses (δ^-)	−0.038 [−0.113, 0.038]	0.963 [0.893, 1.038]
Response noise (θ)	**0.197 [0.071, 0.323]**	**1.218 [1.074, 1.382]**
Constant	−2.257 [−2.711, −1.802]	0.105 [0.066, 0.165]
CV choice	1.369 [1.277, 1.462]	3.932 [3.584, 4.314]
Risk aversion		
Outcome sensitivity (α)	−0.106 [−0.658, 0.446]	0.899 [0.518, 1.563]
Loss aversion (λ)	−0.087 [−0.232, 0.058]	0.917 [0.793, 1.060]
Probability sensitivity (γ)	−0.209 [−0.464, 0.046]	0.812 [0.629, 1.047]
Elevation, gains (δ^+)	**0.397 [0.329, 0.464]**	**1.487 [1.389, 1.591]**
Elevation, losses (δ^-)	**−0.283 [−0.353, −0.213]**	**0.754 [0.703, 0.808]**
Response noise (θ)	−0.090 [−0.204, 0.023]	0.914 [0.815, 1.024]
Constant	−0.730 [−1.169, −0.292]	0.482 [0.311, 0.747]
EV choice	1.376 [1.283, 1.468]	3.958 [3.608, 4.343]

Note: For the analysis of decision quality, the dependent variable was equal to 1 if the participant chose the lottery with the higher expected value (EV) and 0 otherwise. For the analysis of risk aversion, the dependent variable was equal to 0 if the participant chose the lottery with the lower coefficient of variation (CV) and 1 otherwise. Values in brackets are bootstrapped 95% confidence intervals. Results in boldface indicate cumulative prospect theory parameters that are significant predictors.

These results have several implications. One concerns methodology. Many previous studies have focused on choices between a safe and a risky option and have found that older adults are more risk averse than younger adults (for gains but not losses; Best & Charness, 2015; but see Mata et al., 2011). Our findings suggest that the cognitive complexity of the choice stimuli may affect conclusions regarding age differences in risk attitude. In

Table 7. Regression Coefficients for Predicting the Individually Estimated Cumulative Prospect Theory Parameters From Measures of Cognitive Ability and Affect

	Parameter					
Predictor	Outcome sensitivity (α)	Loss aversion (λ)	Probability sensitivity (γ)	Elevation, gains (δ^+)	Elevation, losses (δ^-)	Response noise (θ)
Numeracy	**0.018 [0.011, 0.026]**	0.030 [−0.002, 0.062]	−0.006 [−0.025, 0.012]	−0.041 [−0.112, 0.030]	0.023 [−0.047, 0.093]	**0.059 [0.021, 0.098]**
Fluid abilities	**0.001 [0.000, 0.002]**	−0.001 [−0.006, 0.003]	0.001 [−0.001, 0.004]	**−0.013 [−0.023, −0.003]**	−0.008 [−0.018, 0.002]	**0.012 [0.007, 0.017]**
Crystallized abilities	0.004 [−0.002, 0.010]	**−0.025 [−0.050, −0.001]**	0.005 [−0.009, 0.019]	0.023 [−0.031, 0.077]	−0.029 [−0.083, 0.024]	0.006 [−0.023, 0.035]
Positive affect	0.009 [−0.008, 0.025]	−0.052 [−0.117, 0.014]	−0.007 [−0.045, 0.031]	−0.040 [−0.186, 0.106]	0.011 [−0.132, 0.155]	**−0.089 [−0.167, −0.010]**
Negative affect	−0.008 [−0.026, 0.010]	0.011 [−0.062, 0.084]	−0.019 [−0.061, 0.023]	**−0.201 [−0.363, −0.040]**	0.050 [−0.109, 0.208]	0.033 [−0.053, 0.120]
Constant	0.118 [−0.119, 0.355]	1.921 [0.958, 2.883]	0.419 [−0.138, 0.976]	2.134 [−0.004, 4.271]	2.696 [0.598, 4.795]	0.346 [−0.799, 1.492]

Note: Values in brackets are bootstrapped 95% confidence intervals. Results in boldface indicate significant predictors.

contrast to many previous studies, ours primarily used problems in which both options were risky, so it was impossible for participants to evade computationally effortful risk-return trade-offs by simply choosing, for instance, the option with the safe gain. With these stimuli, older adults tended to be less risk averse than younger adults.

Another set of implications concerns theory. The link between lower levels of negative affect and lower risk aversion that we found is consistent with Forgas's (1995) affect infusion model. Our findings thus highlight the hitherto largely neglected value of this theoretical approach for understanding the effect of age-related motivational changes on risky choice. Further, our computational modeling analysis provides the first stringent test of competing hypotheses regarding how age differences in risky choice map onto the CPT framework. The lack of loss aversion in older adults suggests that motivational reorientation results in a positivity focus (Mather & Carstensen, 2005) rather than in a striving to prevent losses (Depping & Freund, 2012). Our results do not support a dual-process view on aging, according to which age-related increases in reliance on experiential and affective processes result in lower outcome and probability sensitivity (Hess, 2015; Peters et al., 2007). Finally, our finding that older adults showed no loss aversion suggests that what many researchers take as classic regularities in choice (but see Yechiam & Hochman, 2013) may not hold uniformly across the life span.

Note that our finding of lower risk aversion in older adults compared with younger adults contrasts with self-report data indicating that older adults are less likely to engage in risky activities in everyday life (e.g., Josef et al., 2016). In future research, it might therefore be important to study the extent to which older adults' lower self-reported propensity to engage in risky activities, such as buying illegal drugs or going bungee jumping, is driven by age-related differences in the perception of the related risks and rewards or in the opportunity to engage in those activities. Further, given that the present investigation was cross-sectional, another goal will be to examine the development of risky choices from a longitudinal perspective.

Action Editor

Marc J. Buehner served as action editor for this article.

Author Contributions

T. Pachur and R. Mata developed the study concept and study design. Testing and data collection were performed by T. Pachur and R. Mata. T. Pachur performed the data analysis and interpretation. T. Pachur wrote the manuscript, and R. Hertwig and R. Mata provided critical revisions. All the authors approved the final version of the manuscript for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information can be found at http://journals.sagepub.com/doi/suppl/10.1177/0956797616687729

Open Practices

All data have been made publicly available via the Open Science Framework and can be accessed at https://osf.io/35pf6. The complete Open Practices Disclosure for this article can be found at http://journals.sagepub.com/doi/suppl/10.1177/0956797616687729. This article has received the badge for Open Data. More information about the Open Practices badges can be found at http://www.psychologicalscience.org/publications/badges.

Note

1. The formula for the coefficient of variation (σ) is as follows: $\sigma = \sqrt{\sum_{i=1}^{N} {x_i}^2 \times p_i - \left(\sum_{i=1}^{N} x_i \times p_i\right)^2}$, where N is the number of outcomes x with probabilities p.

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