Routledge
Taylor & Francis Group

Journal of Clinical and Experimental Neuropsychology

ISSN: 1380-3395 (Print) 1744-411X (Online) Journal homepage: http://www.tandfonline.com/loi/ncen20

Age-differences in cognitive flexibility when overcoming a preexisting bias through feedback

Cristina G. Wilson, Amy T. Nusbaum, Paul Whitney & John M. Hinson

JOURNAL OF CLINICAL AND EXPERIMENTAL NEUROPSYCHOLOGY, 2017
https://doi.org/10.1080/13803395.2017.1398311

Age-differences in cognitive flexibility when overcoming a preexisting bias through feedback

Cristina G. Wilson, Amy T. Nusbaum, Paul Whitney and John M. Hinson

Department of Psychology, Washington State University, Pullman, WA, USA

ABSTRACT

Introduction: Older adults are often worse than younger adults at adapting to changing situational demands, and this difference is commonly attributed to an age-related decline in acquiring and updating information. Previous research on aging and cognitive flexibility has used measures that require adapting to novel associations learned during a laboratory task (e.g., choice X led to positive outcomes but now leads to negative outcomes). However, in everyday life people must frequently overcome associations based on preexisting beliefs and biases (e.g., you like to eat cake, but your doctor said to limit your sugar intake). The goal of the present study was to examine possible age-differences in overcoming a preexisting bias and determine whether age-related changes in the acquisition and updating of information influence this form of flexibility.
Method: Older (n = 20) and younger (n = 20) adults completed a novel task in which repeated choices were made between a sure option (gain or loss) and one of two risky options that were initially ambiguous. Optimal performance required overcoming a framing bias toward being risk seeking to avoid a sure loss and risk averse when offered a sure gain. Probe questions assessed knowledge of choice outcomes, while skin conductance assessed physiological reactions to choices and choice outcomes.
Results: Both older and younger adults demonstrated flexibility by reducing the impact of bias over trials, but younger adults had better performance overall. Age-differences were associated with distinct aspects of processing. Young adults had more precise knowledge of choice outcomes and developed skin conductance responses in anticipation of bad choices that were not apparent in older adults.
Conclusions: Older adults showed significant improvement over trials in their ability to decrease bias-driven choices, but younger showed greater flexibility. Age-differences in task performance were based on differences in learning and corresponding representations of task-relevant information.

ARTICLE HISTORY
Received 3 May 2017
Accepted 23 October 2017

KEYWORDS
Older adult; aging; cognitive flexibility; feedback; bias

Our environment in daily life is continually changing, and many of the situations we must adapt to require overcoming preexisting biases. For example, new information about a friend can challenge our beliefs about her (confirmation bias), projects that we have devoted significant time/energy to can require substantial alterations (sunk cost bias), and historically winning investments may begin to experience losses (loss aversion bias). The ability to flexibly overcome preexisting biases may be particularly important for older adults because research suggests they are more vulnerable to some biases than younger adults (Kim, Goldstein, Hasher, & Zacks, 2005; Thomas & Millar, 2012). At present, it is unclear whether older and younger adults differ in their ability to overcome preexisting biases. However, research on a theoretically similar concept, *cognitive flexibility*, may help us to better understand the effect of age on overcoming bias.

Cognitive flexibility is broadly defined as the ability to adapt behavior to changing demands. While overcoming a preexisting bias falls under the scope of this definition, all existing measures of cognitive flexibility involve adapting to an acquired response rather than a preexisting response—that is, participants learn to discriminate between a rewarded stimulus and another one that is not rewarded; then task demands change, and the previously successful response no longer yields reward and must be inhibited while another stimulus is activated. Traditional assessments of cognitive flexibility include task-switching (Kray & Lindenberger, 2000; Lawo, Philipp, Schuch, & Koch, 2012; Wasylyshyn, Verhaeghen, & Sliwinski, 2011), reversal learning (Boutet, Milgram, & Freedman, 2007; Mell et al., 2005; Weiler, Bellebaum, & Daum, 2008), and set-shifting (Hartman, Bolton, & Fehnel, 2001; Head, Kennedy,

CONTACT Cristina G. Wilson cristina.wilson@wsu.edu Department of Psychology, Washington State University, PO Box 644820, Johnson Tower 233, Pullman, WA 99164-2630, USA

Rodrigue, & Raz, 2009; Rhodes, 2004). Older adults tend to exhibit less flexible performance than younger adults on these types of tasks because of a decreased ability to acquire and update relevant information, a finding that is often attributed to age-related declines in deliberative cognitive processing (Hartman et al., 2001; Head et al., 2009; Kray & Lindenberger, 2000; Mell et al., 2005; Weiler et al., 2008). Thus, research with existing measures of cognitive flexibility suggests that older adults will be less adept than young adults at acquiring/updating the information necessary to overcome a preexisting bias. To test this hypothesis, we used a novel measure of cognitive flexibility, the Framed Gambling Task (FGT). Like other measures of cognitive flexibility, the FGT assesses people's ability to alter their cognitive processes based on current circumstances. However, the FGT requires overcoming a preexisting framing bias, rather than a novel association acquired during the task.

In their seminal work on framing bias, Tversky and Kahneman (1981) showed that when disease outbreak intervention programs were framed in terms of lives saved (i.e., 200 people will be saved OR 1/3 probability 600 people will be saved, 2/3 probability 0 people will be saved) participants preferred the sure option over the risky option, but when the same programs were framed in terms of lives lost participants preferred the risky option over the sure option. Subsequent research has shown that both older and younger adults are vulnerable to framing bias (Mayhorn, Fisk, & Whittle, 2002; Rönnlund, Karlsson, Laggnäs, Larsson, & Lindström, 2005) with older adults sometimes showing greater vulnerability (Kim et al., 2005; Thomas & Millar, 2012). Importantly, frame-driven preference reversals are observed not only when risks are probabilistically described, but also when sure options are pitted against risks that are ambiguous and must be learned through feedback (Benjamin & Robbins, 2007; Mishra, Gregson, & Lalumiére, 2012). In the FGT, we use a similar framing manipulation, pitting a sure option (framed as a gain or loss) against one of two risky options that are initially ambiguous (see Figure 1). However, unlike previous research, bias in this task can lead to a normatively incorrect choice, not just a change in risk preference. Advantageous performance in the FGT requires learning through outcome feedback that one risky option, the "good deck," is better (on average) than the sure choice, and the other risky option, the "bad deck," is worse (on average) than the sure choice (see Table 1). Cognitive flexibility is operationalized as increasing the number of advantageous choices on trials where that choice is inconsistent with bias —that is, selecting the good deck over the sure gain, and selecting the sure loss over the bad deck.

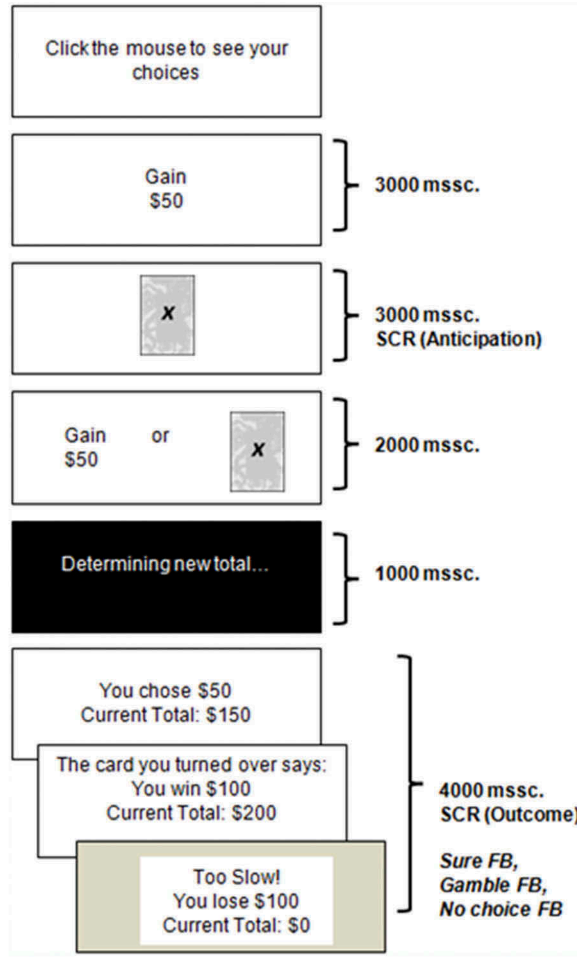

Figure 1. Schematic of Framed Gambling Task (FGT) choice trial. Each trial consists of a choice between a sure option and a risky deck option. If a participant makes their choice within the given time frame, feedback (FB) on their choice (sure or gamble) is provided along with an updated total of their hypothetical monetary winnings. If no choice is made within the time frame then participants are penalized. Timing of trial events is indicated in the figure, along with skin conductance response (SCR) measurement epochs.

Similar to past research with traditional measures of cognitive flexibility, we expected older adults to have less flexible performance in the FGT due to age-related changes in the ability to acquire and update risky option contingencies (cf. Mell et al., 2005; Rhodes, 2004; Wasylyshyn et al., 2011; Weiler et al., 2008). This lower level of flexibility would be manifest as a reduced number of bias-inconsistent advantageous choices in older adults relative to younger adults. In general, age-differences in acquiring/updating risky option contingencies are presumed to be the result of diminished deliberative cognitive processing in older adults (Hartman et al., 2001; Head et al., 2009; Kray & Lindenberger, 2000; Mell et al., 2005; Weiler et al., 2008). However, age-differences could also be due to

Table 1. Possible choice trials on the Framed Gambling Task.

No.	Sure option	Risky option	Advantageous choice	Frame-driven choice	Choice requires cognitive flexibility?
1	Gain \$50	Deck X (Bad)	Gain \$50	Gain \$50	No
2	Gain \$50	Deck Y (Good)	Deck Y (Good)	Gain \$50	Yes
3	Lose \$50	Deck X (Bad)	Lose \$50	Deck X (Bad)	Yes
4	Lose \$50	Deck Y (Good)	Deck Y (Good)	Deck Y (Good)	No

Note. Each deck contains gains and losses based on a fixed set of nine independent outcomes. Deck Y, the good deck, contains outcomes sampled from a normal distribution with a mean of +\$75 and a standard deviation of 100 (−100, −55, −30, 40, 115, 140, 160, 180, 195). The average gain from the good deck is approximately \$138, and the average loss is approximately \$61. Deck X, the bad deck, contains outcomes sampled from a normal distribution with a mean of −\$75 and a standard deviation of 100 (−200, −180, −135, −125, −110, −80, −60, 85, 95). The average loss from the bad deck is approximately \$127, and the average gain is approximately \$90. The advantageous (normatively correct) choice on any trial is to choose the good deck or avoid the bad deck. Cognitive flexibility is required on trials where the advantageous choice is inconsistent with framing bias.

normative maturation of motivational and affective processes. A large literature shows that aging is associated with increased attention to emotional content and a preference to attend to positive information over negative information (Carstensen & Mikels, 2005; Mather & Cartensen, 2005; Peters, Hess, Västfjäll, & Auman, 2007).

To evaluate potential mechanisms underlying age-differences in performance on the FGT, we assessed physiological arousal via skin conductance response and measured knowledge of risky option contingencies by asking participants to estimate the gain and loss outcomes and rate the affective valence of each deck option. We also included an independent measure of processing speed, the Digit–Symbol Substitution Test (DSST; Wechsler, 1955, 1981). The DSST is a widely used measure for describing sample characteristics in studies of age-differences, with typical Age–DSST correlations ranging between −.46 and −.77 (Birren & Morrison, 1961; Doppelt & Wallace, 1955; Kaufman, Reynolds, & McLean, 1989; Royer, Gilmore, & Gruhn, 1981; Salthouse, 1992). Because reductions in processing speed can place constraints on deliberative processing efficiency, age-differences in DSST scores may be related to age-differences in FGT performance.

Method

Participants

There were 40 participants drawn from the community of Pullman, Washington, with 20 older adults between 65 and 85 years of age, and 20 younger adults between 18 and 25 years of age (sample characteristics are summarized in Table 2). Persons who indicated that they had a history of head trauma with permanent brain lesion, had a history of cerebrovascular accident, and/or were currently experiencing psychoactive substance abuse, cognitive dysfunction, or memory complaint did not qualify for participation. Participants were predominantly white (92.5%), native English speakers (95%), reflecting the demographics of the region. Our older adult sample was highly educated, with 84.2% having obtained a bachelor's degree or higher. Despite their high level of education, older adults showed the expected performance deficit on the number of correct responses on the DSST. This result is consistent with a 2004 meta-analysis of age-differences in DSST performance which found a substantial effect of age on the number of correct responses (d = −2.07), independent of years of education (Hoyer, Stawski, Wasylyshyn, & Verhaeghen, 2004). Our older and younger samples had raw DSST scores within the range reported in previous research (Hoyer et al., 2004).

Table 2. Characteristics of younger and older adult samples.

	Young adults		Older adults	
	M (*SD*)	Freq.	*M* (*SD*)	Freq.
N		20		20
Gender (male/female)		3/17		8/12
Race				
White		17		20
Black		1		0
Asian		2		0
Native English speaker		19		19
Education (years)	15.4 (1.6)		17.53 (2.5)	
Highest degree earned				
No graduation		0		1
High school diploma		12		1
Associates		3		1
Bachelors		4		8
Masters		1		2
Doctoral		0		6
BMI	23.36		27.82	
DSST	53.5 (5.22)		36.0 (5.56)	

Note. Body mass index (BMI) was calculated using self-reported height and weight. Digit–Symbol Substitution Test (DSST) scores reflect the number of correct responses.

Procedure

Participants were recruited via poster advertisements in the community. Individuals who expressed interest in participating were contacted by a graduate research assistant over the phone. Verbal consent was obtained, and a brief screening procedure was conducted. Qualifying participants were provided with a secure link to an online survey, which collected information on demographics and education. The online survey also contained questionnaires related to anxiety that were included as part of a separate project. The online survey was administered through Qualtrics (Qualtrics, Provo, UT). Consent was obtained through electronic signature. Following completion of the online survey, participants were recontacted by the graduate research assistant and scheduled for laboratory testing. In the lab, informed consent was obtained by an undergraduate research assistant.

Participants were seated at a computer work station to complete a two-hour task battery, which included the FGT and DSST. The full task battery consisted of additional tasks related to vigilant attention that were included as part of a separate exploratory project. Tasks were ordered pseudo-randomly so the FGT was always completed in the first hour of the battery. At the end of the task battery, participants were debriefed by the undergraduate research assistant. All participants were compensated $50. Ample opportunities for rest breaks between tasks were available throughout the session.

Framed Gambling Task

The FGT was programmed using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). In the task, repeated choices are made between a sure option, a sure gain or sure loss, and one of two risky options, referred to as the good and bad decks. See Figure 1 for a trial schematic. The decks have initially unknown outcomes that must be learned through feedback. The good deck provides mostly gains with occasional losses, while the bad deck provides mostly losses with occasional gains (see Table 1 for list of deck outcomes). One essential feature of the FGT is that there is a normatively correct choice on each trial. On average, the good deck is more advantageous than the sure gain, and the sure loss is more advantageous than the bad deck. Thus, when participants are offered the good deck, the normatively correct choice is to select it, regardless of the sure alternative. But, when participants are offered the bad deck, the normatively correct choice is to select the sure alternative, regardless of whether it is a gain or a loss.

Decks were represented by a rectangle the approximate size of a playing card and distinguishable by color and label. One was light green with a black letter “Y” in the middle, and the other was light blue with a black letter “X” in the middle. Each deck contained gains and losses that were based on a fixed set of nine independent outcomes for a total of 18. Over 72 choice trials, participants had the opportunity to encounter each of the 18 deck outcomes four times. The order presentation of choice options was random, but good and bad decks were used as choices equally often with each sure option. Choices on the FGT were executed using a computer mouse: A left-click selected the sure option, and a right-click selected the gamble option. Participants had 2 s to make their choice. If a choice was made during the allotted time, feedback on the chosen outcome was provided along with an updated monetary total. If no choice was made, participants received feedback telling them they were too slow, and $100 was deducted from their monetary total. This occurred on 1.1% of trials in the younger adult sample and 2.4% of trials in the older adult sample.

Knowledge probes

We asked participants to estimate the average gain and loss from each deck and provide a rating of the deck’s valence, with a low anchor point of −10 labeled “Terrible” and a high anchor point of +10 labeled “Excellent.” Estimations and ratings were collected every 18 trials for a total of four times.

Skin conductance measurement

Skin conductance was recorded using a Psychlab SC5 24 bit system (Contact Precision Instruments, Cambridge, MA). Disposable snap electrodes were attached to the anterior surface of the nondominant hand on the intermediate phalanges of the index and middle fingers. Electrodes contained isotonic gel for consistent ohmic contact and were self-adhesive. Electrodes were attached to the system through leads with pinch connectors. Skin conductance level (SCL) was continuously sampled at 100 Hz. Epochs of SCL were marked in real time for later analysis.

Skin conductance response (SCR) amplitude was computed for two distinct epochs in the FGT: (a) SCR to the presentation of the deck prior to the choice; (b) SCR to the outcome of the choice (see Figure 1). The first epoch reflects anticipation of the forthcoming choice outcome, and the second epoch reflects reaction to the choice outcome (cf. Whitney, Hinson, Wirick, & Holben, 2007). Changes in SCR amplitude were calculated for each epoch by subtracting the baseline SCL from the peak SCL (cf. Hinson, Jameson, & Whitney, 2002). Baseline SCL was the average sample taken during the first 500 ms of the epoch. Peak SCL was the highest sample taken during the remainder of the epoch. Any difference between peak and baseline of less than .01 microsiemens (μS) was considered to be a nonresponse for that trial.

Results

To ensure that the FGT was working as anticipated and that participants' choices were vulnerable to a frame-like bias, we analyzed the proportion of risky choices when faced with a sure loss versus a sure gain. One older adult participant was excluded from analysis because she never sampled from the risky deck options on the FGT. A 2 (frame: gain, loss) × 2 (age: younger, older) repeated measures analysis of variance (ANOVA) revealed that both age groups chose the risky options more frequently when faced with a sure loss frame than with a sure gain, exhibiting the expected bias, $F(1, 37) = 114.36$, $MSE = .030$, $p < .001$, $\eta_p^2 = .76$ (see Figure 2). As a result, participants initially made a higher proportion of advantageous choices consistent with bias than inconsistent. This effect was confirmed by a 2 (bias: consistent, inconsistent) × 2 (age) repeated measures ANOVA of advantageous choices in the first 24 trials, $F(1, 37) = 118.19$, $MSE = .045$, $p < .001$, $\eta_p^2 = .76$.

Next, we examined whether older and younger adults differed in their ability to flexibly overcome bias (see Figure 3). A 2 (bias: consistent, inconsistent) × 3 (trial block: 1–24, 25–48, 49–72) × 2 (age) repeated measures ANOVA of advantageous choices revealed that older adults made fewer advantageous choices overall, $F(1, 37) = 6.72$, $MSE = .075$, $p = .014$, $\eta_p^2 = .15$. However, a significant interaction of Bias × Block, $F(2, 74) = 5.83$, $MSE = .027$, $p = .004$, $\eta_p^2 = .14$, broken down by repeated measure ANOVAs of block, showed that both age groups improved advantageous choices that were inconsistent with bias, $F(2, 116) = 26.19$, $MSE = .036$, $p < .001$, $\eta_p^2 = .31$, to a greater extent than choices that were consistent with bias, $F(2, 116) = 4.69$, $MSE = .014$, $p = .011$, $\eta_p^2 = .08$. Thus, although older adults had generally worse performance than young adults, they were still capable of flexibly overcoming bias.

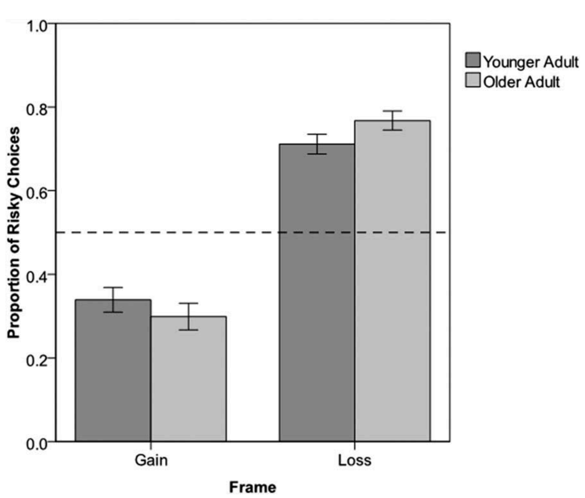

Figure 2. The proportion of risky choices on the Framed Gambling Task (FGT). The figure shows the proportion of risky choices made in the gain frame (left panel) and loss frame (right panel), between younger (dark gray) and older adults (light gray). Error bars are ±1 standard error. A reference line at .5 indicates indifference between frames. Deviations below .5 in the gain frame and above .5 in the loss frame indicate the magnitude of bias.

To evaluate the mechanism(s) underlying age-differences in performance, we first analyzed participants' responses to knowledge probes (see Table 3). Preliminary analyses using a repeated measures ANOVA showed there was no interaction of Age × Trial Block on participants' probe responses. Age-differences in responses appeared after the first block and were maintained over time, with both age groups improving the accuracy of their estimates and ratings. Thus, responses were averaged across blocks for analysis. A multivariate analysis of variance (MANOVA) showed that older adults significantly underestimated both the average loss from the bad deck, $F(1, 36) = 5.21$, $MSE = 2005.91$, $p = .029$, $\eta_p^2 = .13$, and the average gain from the good deck, $F(1, 36) = 18.67$, $MSE = 1210.11$, $p < .001$, $\eta_p^2 = .34$, relative to young adults. However, older and younger adults provided equivalent valence ratings of decks.

Next, we analyzed age-differences in physiological responsiveness. Older and younger adults differed in the development of anticipatory SCR. A 2 (deck) × 2 (age) repeated measures ANOVA showed that younger adults developed strong physiological anticipation to both the good and the bad deck, while older adults only developed anticipation to the good deck, $F(1, 37) = 4.33$, $MSE = .00009$, $p = .044$, $\eta_p^2 = .11$ (see Figure 4). Age-differences in anticipatory SCR were not the result of a general physiological blunting in older adults because a 2 (outcome: gain, loss) × 2 (age) repeated measures ANOVA of SCR during the reception of feedback showed no significant differences; both age groups had strong responses to gain ($M = .08$, $SD = .06$) and loss outcomes ($M = .08$, $SD = .06$) with roughly equal magnitude.

Finally, we analyzed the relationship between DSST scores and FGT performance. We found that DSST scores were positively correlated with overall advantageous choices, $r = .358$, $n = 39$, $p = .013$, and estimates of the average gain from the good deck, $r = .515$, $n = 38$, $p < .001$, and negatively correlated with estimates of the average loss from the bad deck, $r = -275$, $n = 38$, $p = .048$. Thus, the more correct pairings that participants made on the DSST, the better their choice performance and more extreme their estimates of good deck gains and bad deck losses.

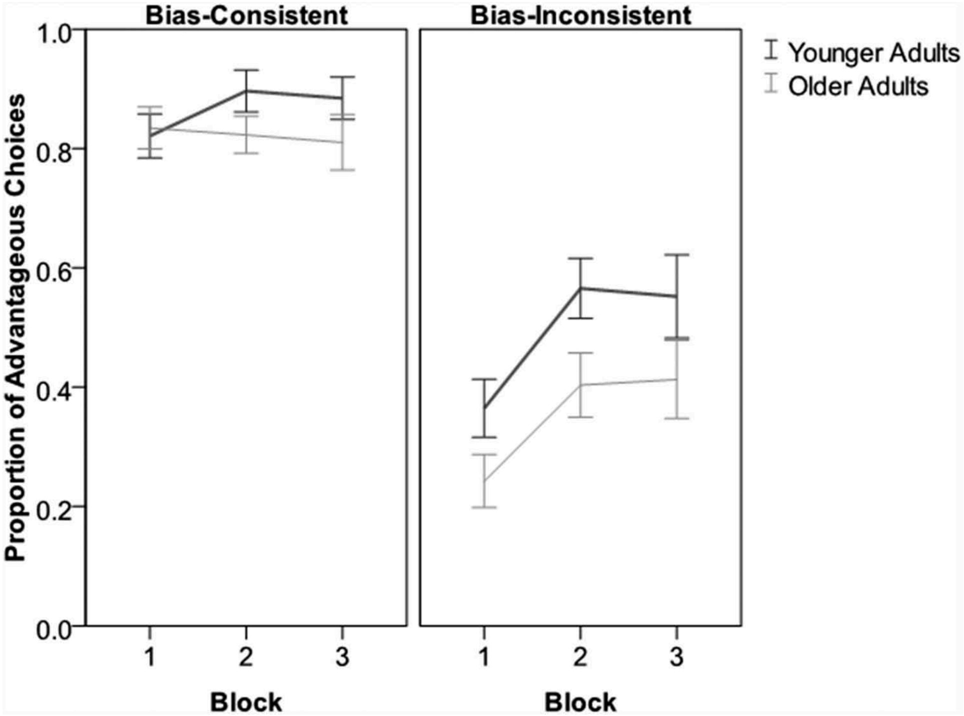

Figure 3. The proportion of advantageous choices on the Framed Gambling Task (FGT). The figure shows the proportion of advantageous choices made that were consistent with bias (left panel) and inconsistent with bias (right panel), across three blocks of 24 trials, between younger (dark gray) and older adults (light gray). Error bars are ±1 standard error.

Table 3. Ratings and estimations of the Framed Gambling Task risky deck options.

	Young adults	Older adults	MANOVA
	M (*SD*)	*M* (*SD*)	*p*
Good deck			
Rating	5.49 (2.35)	5.25 (7.35)	.968
Average gain	96.73 (38.28)	47.91 (30.41)	<.001
Average loss	−53.01 (28.61)	−35.68 (32.98)	.091
Bad deck			
Rating	−4.09 (4.04)	−3.28 (5.30)	.691
Average gain	26.49 (32.48)	28.33 (38.94)	.874
Average loss	−86.66 (44.47)	−53.46 (45.13)	.029

Note. Ratings were on a scale of −10 (Terrible) to +10 (Excellent). The true (and experienced) average values for the good deck were a gain of 138 (138.72) and a loss of 61 (61.63). The true average (and experienced) values for the bad deck were a loss of 127 (127.29) and a gain of 90 (89.44). MANOVA = multivariate analysis of variance.

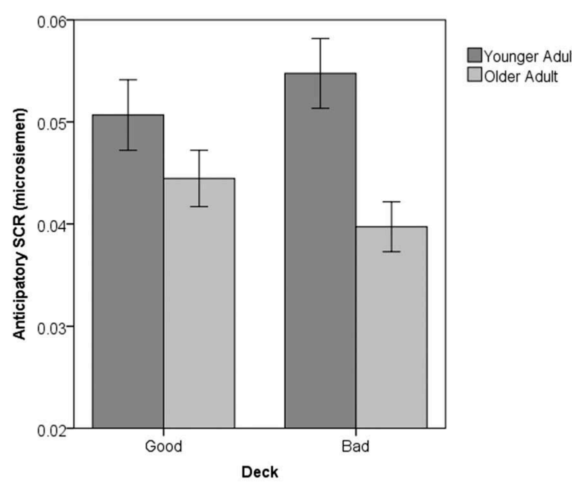

Figure 4. Skin conductance response (SCR) amplitude in anticipation of Framed Gambling Task (FGT) risky choice outcomes. The figure shows SCR amplitude when faced with the good deck (left panel) and bad deck (right panel), between younger (dark gray) and older adults (light gray). Error bars are ±1 standard error.

Discussion

Using a novel task, we built on existing cognitive flexibility research by examining the ability to flexibly overcome a preexisting bias, rather than a transitory, task-learned association. Even though cognitive flexibility in everyday life often involves overcoming preexisting biases, to our knowledge this is the first study to incorporate a preexisting bias and cognitive flexibility into the same context. Both older and younger adults were initially vulnerable to a frame-like bias, but could overcome their bias, at least to some degree, through feedback. However, older adults had worse performance, making fewer advantageous choices overall. Age-differences in performance on the FGT appear to be driven by worse acquisition and updating of risk information in older adults. This is supported by the finding that older adults underestimated both the average gain from the good deck and the average loss from the bad deck.

Since overcoming a preexisting bias is theoretically similar to traditional measures of cognitive flexibility in which participants are asked to overcome an acquired response, it is worthwhile to consider how current theories of cognitive flexibility might account for the results of this study. Classic models of reversal learning posit that it is the violation of expectations about choice outcomes that signals the need to flexibly adapt behavior after a change in contingencies has occurred (e.g., Schoenbaum & Roesch, 2005); cognitive flexibility will be impaired if choice outcome expectations are not developed. Traditionally, the acquisition of expectations has been assumed to arise through computation of a running average during probabilistic reversal learning tasks that are most similar to the FGT (Hare, O'Doherty, Camerer, Schultz, & Rangel, 2008). Thus, models of reversal learning would suggest that cognitive flexibility is reduced in older adults because they do not acquire/update a running average expectation, a computation dependent on good deliberative processing. Our findings of less precise estimations of choice outcomes and blunted physiological anticipation of the bad deck in the older adult sample could reflect an impaired running average expectation about deck outcomes, which would explain why older adults made fewer advantageous choices. Also, because DSST scores were related to knowledge of choice outcomes and advantageous choices on the FGT, our results support the hypothesis that an impaired running average expectation was driven by age-related declines in deliberative processing.

However, despite having less accurate estimations of choice outcomes, older adults did differentiate the good and bad decks in the valence ratings and did demonstrate some flexibility, improving their advantageous choices over time. Thus, they had some form of expectation about the decks (despite imprecise knowledge) that they used to guide behavior. This expectation may have been closer to a "gist" semantic-based expectation, which is commonly found to be preserved in healthy aging (cf. fuzzy trace theory; Brainerd, Reyna, & Howe, 2009). Given this result (i.e., that some flexibility can be observed with imprecise, bottom-line meaning expectations), going forward it is important to explore what form expectancies need to take (e.g., exact running averages, affective-based feelings, etc.) to cue participants when a change occurs. One interesting question raised by the present study is whether it is possible to develop a reward prediction error, defined as the difference between the predicted value of a choice and the value that is actually received (Rescorla & Wagner, 1972), when the value assigned by the individual is in a gist format. Due to the imprecise nature of gist representations, it may be that reward prediction errors are reduced when individuals rely on a gist format, which could account for previous research showing an age-related decline in the ability to generate prediction errors (Samanez-Larkin, Worthy, Mata, McClure, & Knutson, 2014).

An alternative lens through which to view the results of the current study comes from the literature on age-differences in cognitive control. According to Mather and colleagues' *cognitive control hypothesis*, age-related changes in motivational/affective processes push older adults to recruit control processes that strengthen positive stimuli and inhibit/diminish negative stimuli (Mather & Cartensen, 2005; Nashiro, Sakaki, & Mather, 2012). Our finding of physiological anticipation of the good deck but not the bad deck in older adults could therefore reflect a systematic up-regulation of positive information and down-regulation of negative information, which would explain why older adults continued to choose the bad deck when faced with a sure loss. However, it is unclear why down-regulation of negative information and up-regulation of positive information was not also observed in physiological responses to deck outcomes. One possibility is that older adults regulate emotions via top-down control, but not bottom-up control, since the bottom-up detection of threatening information is important for survival. This interpretation is consistent with previous research demonstrating that older adults retain the ability to detect negative stimuli, but do not sustain attention to negative information like younger adults (Mather & Knight, 2006).

A limitation of the current study is that we cannot unequivocally determine whether age-differences in cognitive flexibility are related to older adults' reduced deliberative processing or age-related changes in motivational/affective processing. However, we were able to establish the presence of age-differences in the ability to overcome a preexisting bias, and understanding the mechanisms underlying cognitive flexibility of this variety is an interesting avenue for future research. Another limitation is that the older adult sample used in this study was more educated than the general population of older adults. Thus, the ability to use feedback to overcome a bias that we observed in this study may not be representative of older adults in general. Despite this, we still observed age-differences in cognitive flexibility that are consistent with known differences in younger and older adults' cognitive processing.

In sum, our findings provide converging evidence that age-related changes in the learning of relevant information impact the ability to flexibly overcome a preexisting bias. This type of flexibility has, until now, been unexamined, but it is essential in many of the situations we must adapt to in everyday life, perhaps even more so than the transitory type of flexibility assessed in traditional measures.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Washington State University Proposal Development Stimulus [grant number 121872].

References

Benjamin, A. M., & Robbins, S. J. (2007). The role of framing effects in performance on the Balloon Analogue Risk Task (BART). *Personality and Individual Differences*, *43*, 221–230. doi:10.1016/j.paid.2006.11.026

Birren, J. E., & Morrison, D. F. (1961). Analysis of the WAIS subtests in relation to age and education. *Journal of Gerontology*, *16*, 363–369. doi:10.1093/geronj/16.4.363

Boutet, I., Milgram, N. W., & Freedman, M. (2007). Cognitive decline and human (Homo sapiens) aging: An investigation using a comparative neuropsychological approach. *Journal of Comparative Psychology*, *121*(3), 270–281. doi:10.1037/0735-7036.121.3.270

Brainerd, C. J., Reyna, V. F., & Howe, M. L. (2009). Trichotomous processes in early memory development, aging, and neurocognitive impairment: A unified theory. *Psychological Review*, *116*(4), 783–832. doi:10.1037/a0016963

Carstensen, L. L., & Mikels, J. A. (2005). At the intersection of emotion and cognition: Aging and the positivity effect. *Current Directions in Psychological Science*, *14*(3), 117–121. doi:10.1111/j.0963-7214.2005.00348.x

Doppelt, J. E., & Wallace, W. L. (1955). Standardization of the wechsler adult intelligence scale for older persons. *The Journal of Abnormal and Social Psychology*, *51*(2), 312–330. doi:10.1037/h0044391

Hare, T. A., O'Doherty, J., Camerer, C. F., Schultz, W., & Rangel, A. (2008). Dissociating the role of the orbitofrontal cortex and the striatum in the computation of goal values and prediction errors. *Journal of Neuroscience*, *28* (22), 5623–5630. doi:10.1523/JNEUROSCI.1309-08.2008

Hartman, M., Bolton, E., & Fehnel, S. E. (2001). Accounting for age differences on the wisconsin card sorting test: Decreased working memory, not inflexibility. *Psychology and Aging*, *16* (3), 385–399. doi:10.1037//0882-7974.16.3.385

Head, D., Kennedy, K. M., Rodrigue, K. M., & Raz, N. (2009). Age differences in perseveration: Cognitive and neuroanatomical mediators of performance on the Wisconsin card sorting test. *Neuropsychologia*, *47*(4), 1200–1203. doi:10.1016/j.neuropsychologia.2009.01.003

Hinson, J. M., Jameson, T. L., & Whitney, P. (2002). Somatic markers, working memory, and decision making. *Cognitive, Affective & Behavioral Neuroscience*, *2*(4), 341–353. doi:10.3758/CABN.2.4.341

Hoyer, W. J., Stawski, R. S., Wasylyshyn, C., & Verhaeghen, P. (2004). Adult age and digit symbol substitution performance: A meta-analysis. *Psychology and Aging*, *19*(1), 211–214. doi:10.1037/0882-7974.19.1.211

Kaufman, A. S., Reynolds, C. R., & McLean, J. E. (1989). Age and WAIS-R intelligence in a national sample of adults in the 20- to 74-year age range: A cross-sectional analysis with educational level controlled. *Intelligence*, *13*(3), 235–253. doi:10.1016/0160-2896(89)90020-2

Kim, S., Goldstein, D., Hasher, L., & Zacks, R. T. (2005). Framing effects in younger and older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *60*(4), P215–P218. doi:10.1093/geronb/60.4.P215

Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and Aging*, *15*(1), 126–147. doi:10.1037/0882-7974.15.1.126

Lawo, V., Philipp, A. M., Schuch, S., & Koch, I. (2012). The role of task preparation and task inhibition in age-related task-switching deficits. *Psychology and Aging*, *27*(4), 1130–1137. doi:10.1037/a0027455

Mather, M., & Cartensen, L. L. (2005). Aging and motivated cognition: The positivity effect in attention and memory. *Trends in Cognitive Sciences*, *9*(10), 496–502. doi:10.1016/j.tics.2005.08.005

Mather, M., & Knight, M. R. (2006). Angry faces get noticed quickly: Threat detection is not impaired among older adults. *The Journals of Gerontology: Series B*, *61*(1), 54–57. doi:10.1093/geronb/61.1.P54

Mayhorn, C. B., Fisk, A. D., & Whittle, J. D. (2002). Decisions, decisions: Analysis of age, cohort, and time of testing on framing of risky decision options. *Human Factors*, *44*(4), 515–521. doi:10.1518/0018720024496935

Mell, T., Heekeren, H. R., Marschner, A., Wartenburger, I., Villringer, A., & Reischies, F. M. (2005). Effect of aging on stimulus-reward association learning. *Neuropsychologia*, *43* (4), 554–563. doi:10.1016/j.neuropsychologia.2004.07.010

Mishra, S., Gregson, M., & Lalumiére, M. L. (2012). Framing effects and risk-sensitive decision making. *British Journal of Psychology*, *103*, 83–97. doi:10.1111/j.2044-8295.2011.02047.x

Nashiro, K., Sakaki, M., & Mather, M. (2012). Age differences in brain activity during emotion processing: Reflections of age-related decline or increased emotion regulation? *Gerontology*, *58*(2), 156–163. doi:10.1159/000328465

Peters, E., Hess, T. M., Västfjäll, D., & Auman, C. (2007). Adult age differences in dual information processes. *Perspectives on Psychological Science*, *2*(1), 1–23. doi:10.1111/j.1745-6916.2007.00025.x

Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current research and theory* (pp. 64–99). New York: Appleton-Century-Crofts.

Rhodes, M. G. (2004). Age-related differences in performance on the wisconsin card sorting test: A meta-analytic review. *Psychology and Aging*, *19*(3), 482–494. doi:10.1037/0882-7974.19.3.482

Rönnlund, M., Karlsson, E., Laggnäs, E., Larsson, L., & Lindström, T. (2005). Risky decision making across three arenas of choice: Are younger and older adults differently susceptible to framing effects? *The Journal of General Psychology*, *132*(1), 81–93. doi:10.3200/GENP.132.1.81-93

Royer, F. L., Gilmore, G. C., & Gruhn, J. J. (1981). Normative data for the symbol digit substitution task. *Journal of Clinical Psychology*, *37*(3), 608–614.

Salthouse, T. A. (1992). What do adult age differences in the digit symbol substitution test reflect? *Journal Of Gerontology: Psychological Sciences*, *47*(3), 121–128.

Samanez-Larkin, D. R., Worthy, D. D., Mata, R., McClure, S. M., & Knutson, B. (2014). Adult age differences in frontostriatal representation of prediction error but not reward outcome. *Cognitive, Affective, & Behavioral Neuroscience*, *14*(2), 672–682. doi:10.3758/s13415-014-0297-4

Schoenbaum, G., & Roesch, M. (2005). Orbitofrontal cortex, associative learning, and expectancies. *Neuron*, *47*(5), 633–636. doi:10.1016/j.neuron.2005.07.018

Thomas, A. K., & Millar, P. R. (2012). Reducing the framing effect in older and younger adults by encouraging analytic processing. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *67B*(2), 139–149. doi:10.1093/geronb/gbr076

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science*, *211*(4481), 453–458. doi:10.1126/science.7455683

Wasylyshyn, C., Verhaeghen, P., & Sliwinski, M. J. (2011). Aging and task switching: A meta-analysis. *Psychology and Aging*, *26*(1), 15–20. doi:10.1037/a0020912

Wechsler, D. (1955). *Manual for the wechsler adult intelligence scale*. New York: The Psychological Corporation.

Wechsler, D. (1981). *Manual for the wechsler adult intelligence scale—Revised*. New York: Psychological Corporation.

Weiler, J. A., Bellebaum, C., & Daum, I. (2008). Aging affects acquisition and reversal of reward-based associative learning. *Learning & Memory*, *15*(4), 190–197. doi:10.1101/lm.890408

Whitney, P., Hinson, J. M., Wirick, A., & Holben, H. (2007). Somatic responses in behavioral inhibition. *Cognitive, Affective & Behavioral Neuroscience*, *7*(1), 37–43. doi:10.3758/CABN.7.1.37