Adult age differences in the influence of financial skewness on choice and neural activity

Comment [KS1]: More interesting title?

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Abstract

Older adults are disproportionately targeted by financial fraud attempts that promise rare opportunities for high returns (positively-skewed risks). Sensitivity to skewed risks may be a factor that contributes to vulnerability to fraud. Here we examined adult age differences in choice and neural activity while 34 individuals chose to reject (certain $0) or accept symmetric (50% chance of modest win or loss), positively-skewed (25% chance of large gain), or negatively-skewed (25% chance of large loss) risky gambles while undergoing fMRI. Logistic regression analyses of the behavioral data revealed that older adults relative to younger adults were more likely to accept positively-skewed gambles and less likely to accept negatively-skewed gambles. Replicating previous research in young adults, there were main effects of nucleus accumbens (NAcc) and anterior insula (INS) neural activity on choice such that increased activity in the NAcc increased acceptance of gambles while increased activity in the INS decreased acceptance of gambles. However, both of these main effects were qualified by significant interactions with age such that the effects of activity in both of these regions on gambling were reduced in older adults. Whole-brain analyses revealed age by condition (positive vs. negative skew) interactions in dorsolateral and inferior frontal cortex but activity in these regions did not significantly predict choice. An exploratory analysis revealed that individual differences in INS activity were correlated with individual differences in self perceptions of fraud vulnerability. Collectively, these results suggest that age influences the willingness to accept skewed gambles, that there are age differences in the influence of the NAcc and INS on skewed choice, and that individual differences in INS activity during decision making may be a marker of the likelihood of taking skewed risks in the real world.

Introduction

Individuals encounter many potentially risky decisions every day from deciding with whom to spend time, whether to change careers, or how to spend or invest financial assets. Nearly all long-term financial decision making is risky. Although much research on and models of decision making examine how the expected value (mean) and risk (variance) of a potential investment influence choice, much less research has focused on how skew (e.g., low probability of a large outcome) influences choice.

Recently, neuroscientists have begun to examine the influence of skewed gambles on self-reported affect, gambling preferences, and neural activity (Wu, Bossaerts, & Knutson, 2011). In a sample of young adults, they found that compared to symmetric gambles with equivalent expected value, positively-skewed gambles elicited positive arousal and were preferred by participants while negatively-skewed gambles elicited more negative arousal and were less preferred. In the brain, they found that skewed gambles elicited more activation in the anterior insula (INS) than symmetric gambles and positively-skewed gambles elicited more activation in the nucleus accumbens (NAcc) than negatively-skewed gambles. Critically, they found that functional neural activity in the NAcc and self-reported positive arousal predicted individual preferences for positively-skewed gambles. A more recent study showed that structural connections between the INS and NAcc were related to individual differences in preferences for skew, further clarifying the dual roles of NAcc and INS on choice (Leong, Pestilli, Wu, Samanez-Larkin, & Knutson, 2016).

The limited research on skewed risk taking has focused primarily on decisions made in young adulthood or has not examined age differences. However, it may be even more critical to study the influence of skew on decision making in older age. In everyday life, older adults face many skewed risks. Should they invest in a new company that promises a large, but perhaps unlikely, return on investment (positive skew)? Should they go for a walk with their grandchild, even if doing so may increase their chances of suffering an unlikely, yet possibly debilitating, fall (negative skew)? Studying skewed risk taking across adulthood may be particularly important as older adults are often targets of investment fraud attempts promising rare opportunities for high returns (MetLife Mature Market Institute, 2011).

Although research on skewed risk taking in old age is lacking, there is a large and growing literature on adult age differences in risky decision making in general. However, the findings are mixed (Best & Charness, 2015; Mata, Josef, Samanez-Larkin, & Hertwig, 2011). While some studies suggest older adults take less risk compared to younger adults (e.g Rolison, Hanoch, & Wood, 2012), some studies show that older adults take more risk (e.g. Zamarian, Sinz, Bonatti, Gamboz, & Delazer, 2008), and still others find no age differences (e.g.Wood, Busemeyer, Koling, Cox, & Davis, 2005). It has been suggested that some of the discrepancies in findings are due to differences in the cognitive demands of the tasks (Mata et al 2011), but many of these tasks also vary in the skewness of the available options. It is possible that older adults may be more or less likely to take risks depending on skew. Studying age differences in skewed risk taking may improve our understanding of risky decision making across adulthood.

There is also reason to predict that age differences in skewed risk taking will depend on the direction of the skewness (i.e., positive or negative). Studies of cognitive aging have documented a tendency in older adults to attend to and remember information with a positive valence (Carstensen & Mikels, 2005; Mather & Carstensen, 2005). This "positivity effect" could lead older adults to differentially respond to positively-skewed and negatively-skewed gambles. Similarly, prior neuroimaging research has shown an interaction between age and valence in both the NAcc and the INS during the processing of financial gains and losses. Activation of the NAcc in anticipation of financial gains is preserved with age (Samanez-Larkin et al., 2007), and functional neural signal variability in the NAcc is related to age differences in making excessively risky financial decisions (Samanez-Larkin, Kuhnen, Yoo, & Knutson, 2010). Studies have also documented age-related reductions in INS activation in anticipation of financial losses (Samanez-Larkin et al., 2007), in response to untrustworthy faces (Castle et al., 2012), and in response to unfair social economic offers (Harlé & Sanfey, 2012). Collectively, these findings led to us to predict that age would influence both behavioral and neural responses to skewed gambles.

The present study examines adult age differences in choice behavior while individuals chose to accept or reject symmetric, positively-skewed, or negatively-skewed risky gambles while undergoing fMRI. Our first aim was to determine whether age influenced choice behavior. Based on the age-related positivity effect (Carstensen & Mikels, 2005; Mather & Carstensen, 2005), we predicted that compared to symmetric gambles, older adults would be more likely to accept positively-skewed gambles and less likely to accept negatively-skewed gambles. Our second aim was to determine whether or not age differences in neural activity related to choice behavior. Based on previous research in young adults, we predicted that NAcc activity would be positively related to acceptance of skewed gambles (Wu et al., 2011), and that this relationship would be preserved with age (Samanez-Larkin et al., 2007; Samanez-Larkin, Worthy, Mata, McClure, & Knutson, 2014). We also predicted that INS activity would be negatively related to acceptance of skewed gambles, and that this relationship would be reduced with age (Castle et al., 2012; Harlé & Sanfey, 2012; Samanez-Larkin et al., 2007). A final, more exploratory aim was to examine whether choice behavior or neural activity during decision making was related to the likelihood of taking skewed financial risks in real life. We predicted that acceptance of skewed gambles would be related to financial fraud vulnerability.

Method

Participants

Thirty-four healthy adults (Age: *M* = 47.9, *Range* = 18-85) were recruited from the San Francisco Bay Area community to complete a study at the Stanford Center for Cognitive and Neurobiological Imaging. A subset of these participants' behavioral and fMRI data were included in another publication that did not examine age differences (Leong et al 2016). Prior to participation, informed consent was obtained and then participants completed a battery of neuropsychological, personality, and self-report measures. Following these tests (but often on a second day), participants underwent the neuroimaging session described below. All participants were compensated with a flat rate of $20 per hour, as well as the total amount earned on the gambling tasks. The Stanford Medical School Institutional Review Board approved all procedures.

Behavioral Task

During functional neuroimaging, participants completed a variant of the gambling task used by Wu, Bossaerts, & Knutson (2011). On each of 72 trials, participants viewed a gamble (2s), selected an option and viewed the chosen option (4s), and the received feedback (2s; Figure 1a). Trials were separated by intra-trial intervals ranging from 2-6 seconds. Both the spatial location of the gamble (top or bottom circle) and the response associated with each circle (left or right) were counterbalanced across trials.

Three types of gambles were used: symmetric, positive-skew and negative-skew gambles. For symmetric gambles, there was an equal probability (50%) of winning or losing a moderate amount of money ($3.05). For positive-skew gambles, there was a low probability (25%) of winning a large amount ($5.25) coupled with a high probability (75%) of losing a small amount ($1.75). Negative-skew gambles were the opposite; there was a low probability (25%) of losing a large amount ($5.25) coupled with a high probability of gaining a small amount ($1.75). Critically, the expected value of each gamble was set to $0, making it equivalent to the alternative options, and the variance was equated across all trials ($\sigma^2 = 9.19$). Participants completed 24 trials of each gamble type, presented in pseudorandom order.

Prior to beginning the task, participants were endowed with $10. On each trial, if the gamble was chosen, the gamble was played out and the results were added to the cumulative total. During the feedback period, the outcome of the gamble, or $0, was displayed on screen along with the participant's cumulative total. As mentioned above, this cumulative total was added to the hourly rate as compensation.

Real-Life Fraud Susceptibility

Self-report was used to assess fraud susceptibility. Participants were asked about their ability to detect fraud and resist persuasion, including: (a) “How likely are you to make a fraudulent investment?”, (b) “How able are you to detect a fraudulent investment?”, and (c) “How able are you to resist high-pressure sales tactics when buying investments?” Participants responded using a 7-item scale ranging from “not at all likely/able to detect/able to resist” to “very likely/able to detect/able to resist.”

fMRI Acquisition and Analysis

Brain images were acquired with a 3T GE Discovery MR750 scanner using a thirty-two-channel head coil. Forty-six 2.9mm thick slices (in-plane resolution 2.9 x 2.9 mm) extending from the mid-pons to the top of the skull were acquired with an axial interleaved scheme. Functional scans were acquired using a T2*-weighted gradient pulse sequence (repetition time =2s, echo time = 24 ms, flip angle = 77 degrees). Anatomical scans, which were used for localization and coregistration of functional data, were acquired using T1-weighted spoiled grass sequence (repetition time = 7.2 ms, echo time = 2.3 ms, flip angle = 12 degrees, 0.9 mm isotropic voxels).

Analysis of functional neuroimaging data was conducted using Analysis of Functional Neuroimages (AFNI) software (Cox, 1996). Preprocessing of time series data included slice-time correction to account for non-simultaneous acquisition, motion correction in six directions to account for motion between volumes, spatial smoothing to minimize anatomical differences (FWHM = 4mm), normalization to convert to percent signal change relative to the mean activation for the entire experiment, and high-pass filtering remove slow trends. For each participant, preprocessed time series data were analyzed with multiple regression models in AFNI. The models included two contrasts of interest: (1) skewed versus symmetric, and (2) positive versus negative skew. Before inclusion in the regression models, these contrasts were convolved with a gamma function as a proxy for the hemodynamic response. The regression models also included nine covariates: residual motion (in six dimensions), white matter and cerebral spinal fluid masks, and polynomial trends across the experiment. For each contrast of interest, *T*-statistic maps were transformed in *Z*-scores, and spatially normalized by warping into Taliarach space.

The first set of analyses examined age differences in two primary regions of interest, the bilateral nucleus accumbens (NAcc) and bilateral anterior insula (INS), based on previous research (Wu et al., 2011). For each region of interest we examined age differences in activation and the relationship between activation in these regions and behavior. The second set of analyses used linear regression to examine age differences across the whole brain. At the whole-brain level, voxel-wise statistical thresholds were set to $p < .005$, uncorrected. The minimum cluster size of 40 contiguous 2.9-mm^3 voxels for a cluster-level correction of $p < .05$ was estimated using AFNI's AlphaSim. Additional regions of interest were specified by placing 8-mm diameter spheres centered on the peak voxel of significant clusters that emerged from this analysis. Activation timecourses were extracted from each ROI, and follow-up analyses examined how age modulated activation during the choice phase of each trial (i.e. signal from TRs 4 to account for the hemodynamic response).

Statistical Analysis

We used multilevel binary logistic regression to examine the effects of experimental conditions, age, and brain response on gambling behavior with intercepts allowed to vary across participants. This approach allowed us to take into account multiple within-subject conditions. Trial type (positive skew vs. all others, negative skew vs. all others), previous outcome (win vs. all others, loss vs. all others), age (as a continuous predictor), and all binary interactions between these terms were included as predictors in the first stage model (Model 1). In the second stage model (Model 2), mean percent signal change from two a priori regions, the NAcc and aINS, and the interaction between these terms and age, were added. In the final model, mean percent signal change from two regions identified from the whole brain analysis, and the interaction between these terms and age, were added (Model 3).

Results

As displayed in Table 2, there were significant effects of experimental conditions and age on gambling behavior (Model 1). Specifically, there were main effects of both positive skew and negative skew on gambling behavior, such that participants were more willing to accept positively-skewed gambles and less willing to accept negatively-skewed gambles. There was also a main effect of previous loss, with participants being more willing to accept gambles after losing on the previous trial. However, these main effects were qualified by significant interactions. For negatively-skewed choices, there was also a significant interaction with previous outcome: participants were more likely to accept a negatively-skewed gamble after a win and less likely to accept a negatively-skewed gamble after a loss. There was an interaction between age and both positive and negative skew, with older adults being more willing to accept positively skewed gambles and less willing to accept negatively skewed gambles compared to younger adults (Figure 1b).

As displayed in Figure 2, adding information about brain activity in *a priori* regions of interest significantly increased the ability to predict gambling behavior (Table 2, Model 2). All of the significant effects described for Model 1 (behavior only) remained significant in Model 2 (behavior + brain). Mean percent signal change in the bilateral nucleus accumbens (NAcc) was associated with increased acceptance of gambles, while signal change in the bilateral anterior insula (INS) was associated with decreased acceptance of gambles. However, both of these effects were qualified by significant interactions with age: in both regions, the effect of brain activity on gambling behavior was reduced in older adults. Although we identified additional brain regions in our whole brain analysis of age differences (Supplementary material), mean percent signal change from these regions was not significantly related to choice and did not explain additional variance in gambling behavior (Table 2, Model 3). Thus, the age differences in these regions did not appear to be related to the age differences in decision making.

In an exploratory set of analyses, we also investigated whether or not gambling behavior and neural activity were associated with real-life financial outcomes. We examined the partial correlations between gambling behavior and brain activity during gambling from a priori regions of interest while holding age constant. As displayed in Table 3, there was an association between signal change in the anterior insula during negatively-skewed trials and an individual's belief that they would make fraudulent investments such that decreased insular activity is associated with increased likelihood to make a fraudulent investment. No other behavioral or neural predictors were associated with fraud susceptibility.

Discussion

This study investigated adult age differences in choice and neural activity during skewed risky decision making, and how these measures related to potential fraud susceptibility in everyday life. The behavioral and neural findings across age were consistent with previous research in young adults. Our findings that increased activity in the NAcc increased skewed risk taking while increased activity in the INS decreased skewed risk taking are consistent with the role of these regions in affective processing (Knutson, Katovich, & Suri, 2014; Kuhnen & Knutson, 2005) and the influence these regions have on choice (Knutson & Huettel, 2015).

The use of an adult life-span sample allowed us to examine whether or not these relationships remained constant throughout adult development. We found that age interacted with the valence of skewed gambles: older adults were more likely to accept positively-skewed gambles and less likely to accept negatively-skewed gambles compared to younger adults. Need to come back to intro point about how this could clarify previous inconsistencies in aging risky decision making literature. As predicted, these valence effects are consistent with the age-related positivity effect (Carstensen & Mikels, 2005; Mather & Carstensen, 2005). Prior studies examining how this

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developmental trend influences decision making have focused on how positivity shapes ~~information selection~~attention, ~~and~~ recall and satisfaction (Kim, Healey, Goldstein, Hasher, & Wiprzycka, 2008; Löckenhoff & Carstensen, 2007; Mather & Johnson, 2000), but have not focused on ~~how positivity may actually bias~~ the actual decisions made by participants. Despite the fact that all decision options used in this study were objectively equivalent (in expected value), ~~in our experiment~~ older adults demonstrated a bias towards positively~~-~~skewed gambles and away from negatively~~-~~skewed gambles. This provides more direct evidence an age-related positivity effect in choice behavior. This suggests that a focus on positive information, in particular the large potential gains in the positively-skewed gambles used here, may actually bias decisions and~~, providing more direct evidence an age-related positivity effect in choice behavior.~~ may make older adults more susceptible to fraudulent investments and lotteries in real life.

<Need paragraph on negative skew and loss avoidance here> End with point about buying insurance below at end of para> Point out practical implications - ~~that pos skew increase possibly suggests more likely to make fraudulent investments and~~ neg skew decrease suggests older more likely to maintain or increase insurance (protect assets and avoid loss).

Age differences were also found in how the effects of brain activity on choice behavior. Compared to young adults, the effects of activation in the NAcc and INS on skewed risk taking were reduced in older adults. Although the reduced influence of INS on risk taking with age was predicted, the reduced influence of NAcc on risk taking was not. Based on prior research showing age constancy in NAcc response (Samanez-Larkin et al., 2007, 2014; Spaniol, Bowen, Wegier, & Grady, 2015), we predicted that the influence of the NAcc on choice behavior would be preserved with age. Furthermore, these results do not directly explain the behavioral interaction described above. (add explanation here) To identify regions that might better explain the age by valence interaction in behavior, we conducted more exploratory whole-brain analyses of age by valence interactions. This analysis identified two lateral cortical regions that showed similar (but opposite) interactions with age. This pattern of activation may be viewed as partially consistent with dual-systems models of the decision making (Morewedge & Kahneman, 2010), where more lateral cortical regions inhibit activity in medial and subcortical regions (Daw, Niv, & Dayan, 2005; Sanfey, Loewenstein, McClure, & Cohen, 2006). However, we don't have evidence for a direct effect of these lateral cortical regions on the NAcc and INS or on choice. Activity in these regions was not significantly related to acceptance of skewed risks. It is possible that activity in these cortical regions could have an indirect effect on behavior through other brain regions (e.g., NAcc and INS). We examined interaction effects to assess this possibility (not reported here), but did not find statistically significant support for such an effect. The lack of significant effects (multi-way interactions between lateral cortical regions, NAcc/INS, valence, and age) could be due to a lack of statistical power in this relatively small sample. Future research will need to clarify the neural network dynamics underlying the behavioral interaction between age and valence for skewed gambles.

Financial fraud is a large and growing problem in older adulthood. In order to reduce both the instances and consequences of fraud, there is growing interest in both the research community and private sector for identifying risk factors for fraud victimization. This is of particular interest in the aging community, not because older adults are

Comment [GSL3]: It doesn't?

Comment [KS4]: Kim et al examined choice satisfaction; Lockenhoff & Carstensen examined information acquisition and recall; Mather and Johnson examined recall. Based on my reading, none of these studies actually examined the choices made by participants. Happy to rephrase if my wording is unclear or exclude if this is not a relevant point.

Comment [GSL5]: This doesn't seem to explain to me. Seems like a restatement. What about something explaining that enhanced attention to positive aspects might bias estimates of expected value of pos skew risk?

In contrast negative skew effects are not as easy to explain. Positivity effect might suggest that older adults don't pay as much attention to potential downside and would be more likely to take negative skew too. However, some evidence that older adults are highly motivated to avoid loss. Can cite loss prevention literature from Baltes group (probably papers from Freund and maybe one by Natalie Ebner). Can also cite evidence that older adults do avoid negative stims well when the task requires it (Mather & Knight). Also check out Leclerc & Kensinger 2008 so evidence of enhancement of valence in older adults that might explain amplification of both potential gains and losses.

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necessarily more susceptible to fraud attempts (Ross, Grossmann, & Schryer, 2014), but because the negative consequences of fraud in older adulthood are much more extreme (MetLife Mature Market Institute, 2011). This study suggests that examining preference for skewed risks in the laboratory could be a critical predictor of potential fraud susceptibility in everyday life. Although we did not find direct associations between behavioral measures of skewed risk taking and fraud susceptibility, we did find associations with the neural measures. We found that reduced activation in the INS during negatively-skewed gambles was related to self-perception of fraud susceptibility. To our knowledge, this is the first study to show a direct link between brain activity and potential fraud susceptibility. Major weakness is self report. ~~Although significant, analyses were exploratory.~~ Although strong conclusions should not be drawn from exploratory analyses, these results are ~~Still~~ suggestive that neural measures could enable identification of vulnerable individuals before a fraud attempt to implement targeted preventation efforts.

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Table 1

Mean Values (With Standard Deviation in Parentheses) of Participant Characteristics

Variable	
Age (in years)	47.91 (19.5)
Gender	15M/19F
Numeracy Inventory – 9 items	7.79 (1.55)
Numeracy Inventory – 6 items	3.62 (1.02)**
Trail Making Test	28.48 (11.37)
WAIS-III Digit Span Test	18.03 (4.32)*
Letter-Number Sequencing	11.24 (2.95)***
Mini Mental Status Exam	28.70 (1.53)
Shipley Vocabulary	33.44 (4.43)
N	34

Note. Significant relationships with age denoted by asterisks.

*p <.05, ** $p < .01$, *** $p < .001$

Table 2
Logistic Regression Analyses on Gambling Behavior including Subjects as Random Effects

Variables	Contrast/Interaction	Model 1	Model 2	Model 3
Intercept		.32 (.21)	.32 (.21)	.33 (.21)
Skewness	Positive > Symmetric	.24 (.07)***	.19 (.07)**	.19 (.07)**
	Negative > Symmetric	-.63 (.07)***	-.62 (.01)***	-.61 (.07)***
Previous gamble outcome	Loss	.22 (.07)**	.30 (.08)***	.30 (.08)***
	Win	-.06 (.07)	-.07 (.08)	-.08 (.08)
Age		-.07 (.21)	-.05 (.21)	-.06 (.21)
bNAcc			1.13 (.15)***	1.12 (.16)***
bINS			-.45 (.17)**	-.57(.21)**
Left IFG				.13 (.17)
Left dlPFC				.03 (.15)
Previous outcome by Skew Contrasts	Positive x Loss	.16 (.10)	.14 (.10)	.14 (.11)
	Negative x Loss	-.41 (.10)***	-.37 (.10)***	-.37 (.10)***
	Positive x Win	-.16 (.10)	-.14 (.10)	-.14 (.10)
	Negative x Win	.33 (.10)***	.30 (10)**	.30 (.10)
Skew Contrasts by Age	Positive x Age	.63 (.07)***	.66 (.07)***	.66 (.07)***
	Negative x Age	-.45 (.07)***	-.47 (.07)***	-.48 (.07)***
Previous outcome by Age	Loss x Age	.03 (.08)	-.03 (.08)	-.02 (.08)
	Win x Age	.07 (.08)	.10 (.08)	.10 (.08)
Neural activation by Age	bNAcc x Age		-.63 (.14)***	-.64 (.14)***
	bINS x Age		.38 (.15)*	.46 (.18)*
	Left IFG x Age			-.16 (.16)
	Left dlPFC x Age			.08 (.13)
AIC		2726.8	2666.8	2673.2
BIC		2813.7	2776.9	2806.3
Pseudo R^2		0.36	0.39	0.40
Model χ^2			67.95***	1.73

Notes. Unstandardized betas (and standard error) reported. bNAcc = bilateral Nucleus Accumbens; bINS = bilateral anterior insula; IFG = inferior frontal gyrus; dlPFC = dorsolateral prefrontal cortex
$^*p < .05$, $^{**}p<.01$, $^{***}p<.001$

Table 3

Partial correlations between measures of behavior, brain response and real-world fraud susceptibility controlling for age

Conditions	Detect Fraud	Likely Fraud	Resist Fraud
Positive Skew	-0.11	-0.1	0.05
Negative Skew	0.31	-0.26	-0.07
bNAcc on Negative Skew Trials	0.28	-0.13	-0.09
bNAcc on Positive Skew Trials	-0.1	0.16	-0.05
bINS on Negative Skew Trials	0.27	-0.45**	-0.13
bINS on Positive Skew Trials	0.14	-0.32	0.06

Notes. bNAcc = bilateral Nucleus Accumbens; bINS = bilateral anterior insula

*p < .05, **p<.01, ***p<.001

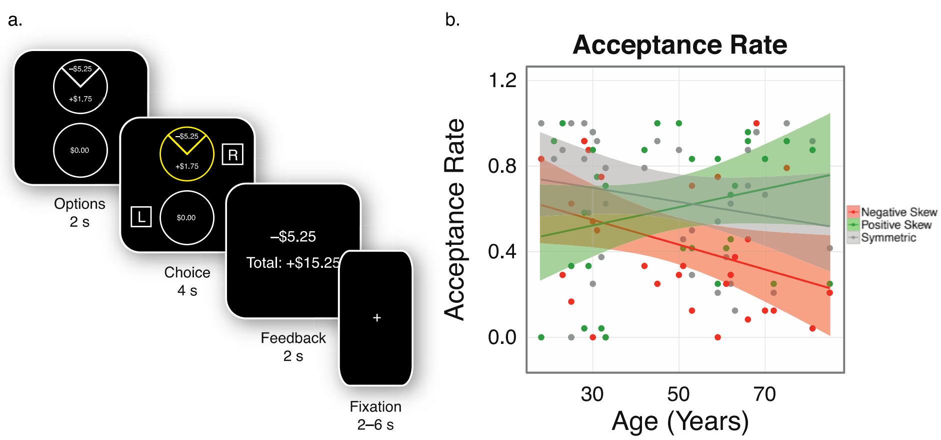

Figure 1. Skewed gambling task. (a) Trial structure for Skewed Gambling Task. (b) Proportion of trials where the gamble was accepted over age by gamble type.

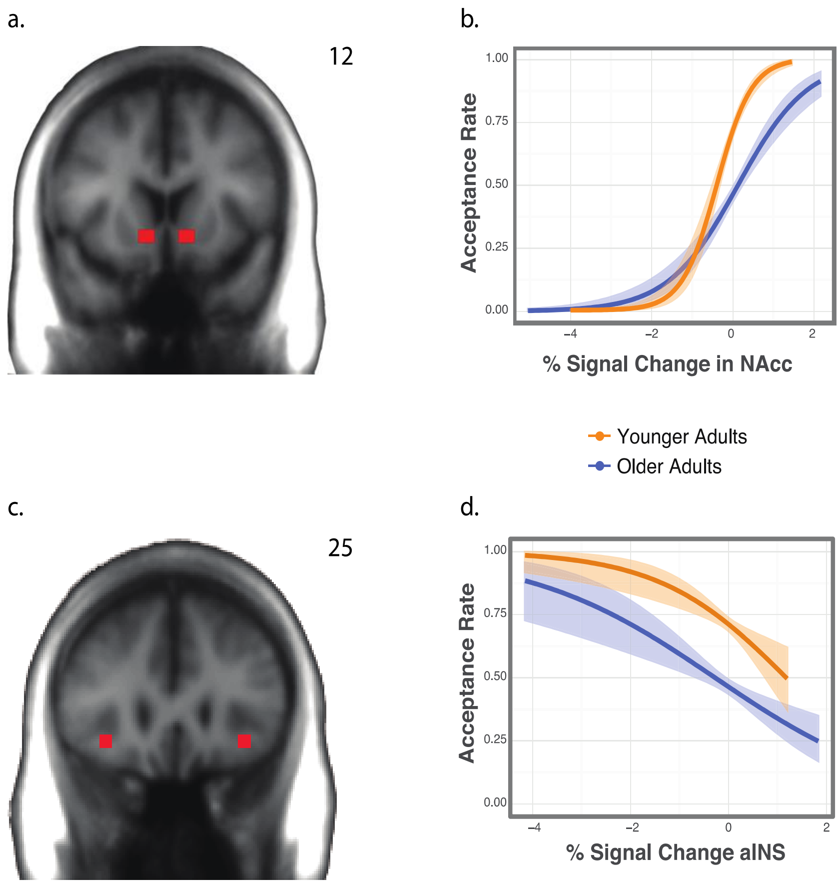

Figure 2. Neural response during Skewed Gambling Task. Top: Nucleus Accumbens (NAcc), Bottom: Anterior Insula (INS). Panels (a) and (c) depict regions of interest. Panels (b) and (d) depict acceptance rate over percent signal change by median-split age group, controlling for other predictors in Model 2..

Acknowledgements

This study was supported by a grant from the Financial Industry Regulatory Authority (FINRA) Investor Education Foundation to B.K. and G.R.S.L. and a National Institute on Aging Pathway to Independence Award (R00-AG042596) to G.R.S.L.