SUPPLEMENTARY MATERIALS

Variability in nucleus accumbens activity mediates age-related suboptimal financial risk taking

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Optimal Portfolio Selection Strategy

During trial τ in each block, a rational risk-neutral agent should pick stock *i* if he/she expects to receive a dividend D^i_τ at least as large as the bond earnings, that is, if:

$E[D^i_\tau|I_{\tau 1}] >= E[D^B_\tau \, |I_{\tau-1}] = 1$, where $I_{\tau-1}$ is the information set up to trial τ-1.

That is: $I_{\tau-1}=\{D^i_t| \, \forall t \leq \tau-1, \forall i \in \{Stock\ T,\ Stock\ R,\ Bond\ C\}\}$.

Let x^i_τ = Pr{ Stock *i* = Good $|I_{\tau-1}\}$. Then:

$E[D^i_\tau|I_{\tau-1}] = x^i_\tau\ [0.5 * 10 + 0.25 * (-10) + 0.25 * 0] + (1 - x^i_\tau)\ [0.5 * (-10) + 0.25 * 10 + 0.25 * 0] = 2.5 * (2x^i_\tau - 1)$

Hence, a risk-neutral agent will pick stock *i* only when his belief x^i_τ is such that:

$2.5 * (2x^i_\tau - 1)>=1 \Leftrightarrow x^i_\tau >= 0.7$

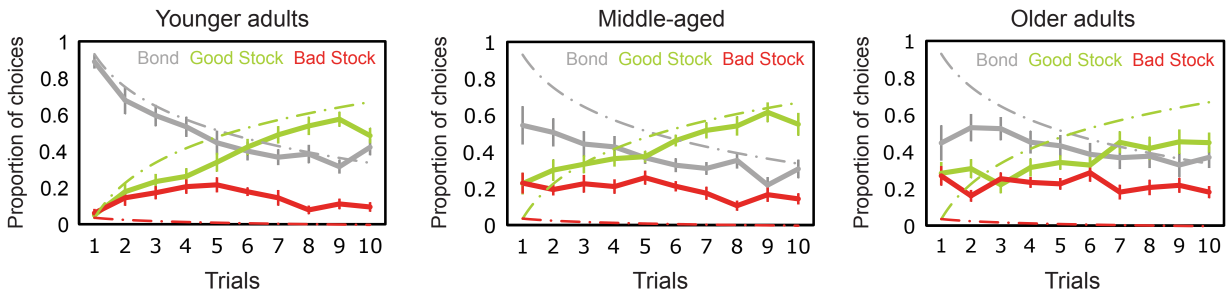
If the agent's beliefs are weak, that is: $x^i_\tau<0.7, \forall i \in \{Stock\ T,\ Stock\ R\}$, then the optimal strategy for the risk-neutral agent is to pick the bond in trial τ.

A rational agent should update his or her beliefs x^i_τ according to Bayes' rule.

In this paper, we refer to the *uncertainty* of a trial τ, defined as $min(x^i_\tau, x^j_\tau)$, where $i,j \in \{StockT, StockR\}$ and $i \neq j$. Hence, the uncertainty is highest (and equal to 0.5) at the beginning of a block, because at that point the probability of either one of the stocks being the good one is 50%. The uncertainty decreases as more information about dividends is revealed and it becomes clearer which stock dominates.

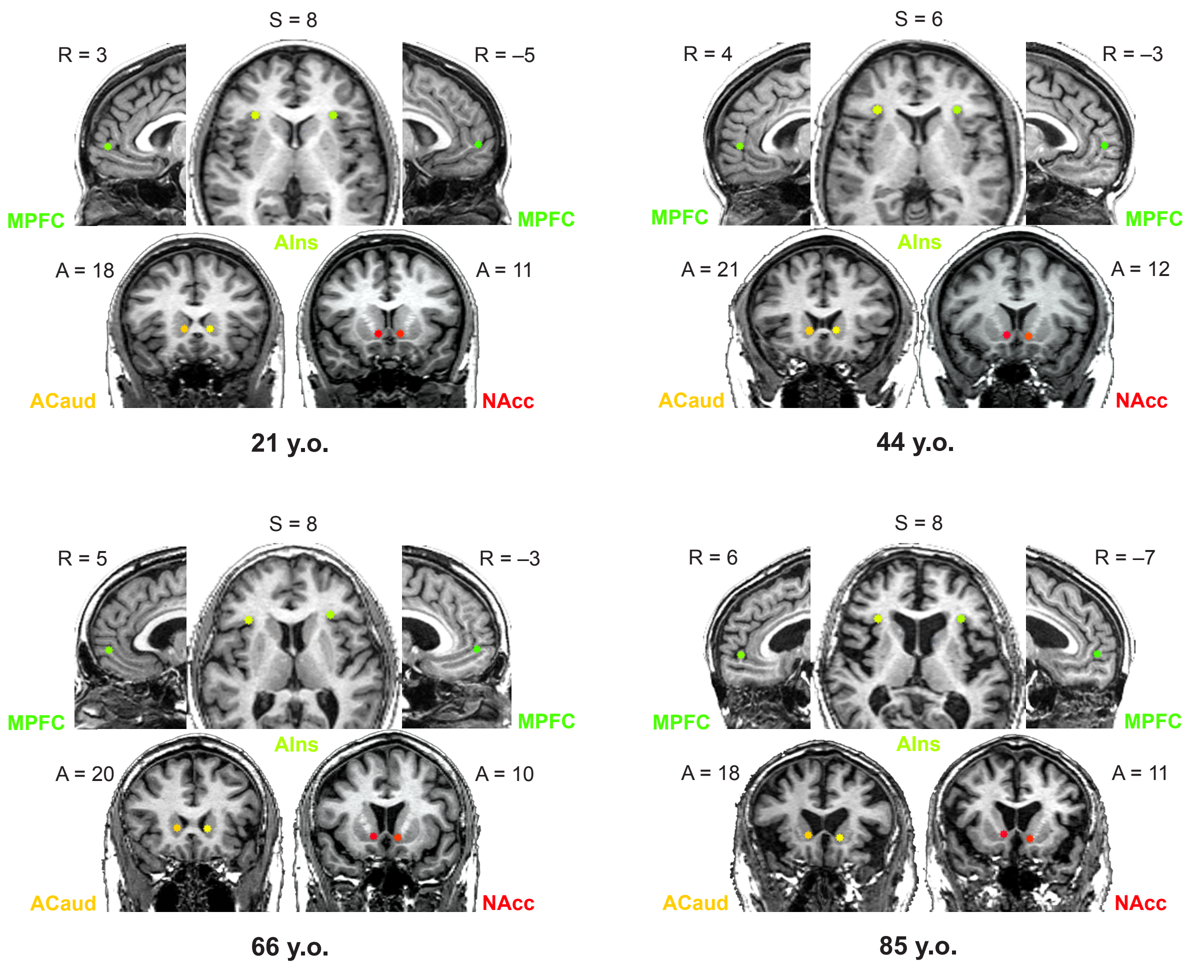
Supplementary Table 1. Individual difference measures. Continuous age sample split into three age groups (younger: 19–35 years old, middle-aged: 39–66 years old, older: 67–85 years old). Standard deviations listed in parentheses.

	Younger Adults	Middle-Aged	Older Adults
Age	26.35 (4.99)	54.97 (8.91)	73.56 (4.94)
Education [# of years]	15.89 (2.66)	15.62 (2.06)	16.17 (2.70)
Satisfaction With Life Scale	17.82 (2.53)	18.06 (4.26)	18.56 (3.55)
Numeracy	6.06 (1.09)	5.94 (1.23)	5.68 (1.86)
Digit Span [WAIS-R]	18.29 (3.41)	18.32 (3.76)	17.61 (9.80)
Letter-Number Sequencing [WAIS-R]	11.33 (3.35)	11.71 (2.82)	9.63 (3.56)
Trails B – Trails A	29.68 (12.79)	30.30 (12.01)	53.33 (28.91)



Supplementary Figure 1. Individual investors approximated the strategy of the rational actor model

Overall at the beginning of each block of ten trials, individuals of all ages showed an initial preference for bonds and then shifted toward a preference for the good stock. This bias becomes weaker with age. Older adults show both a reduced initial preference for the bond at the beginning of a block and a weaker preference for the good stock at the end of a block. Dashed lines are logarithmic trendlines representing the average choices of the rational actor model.



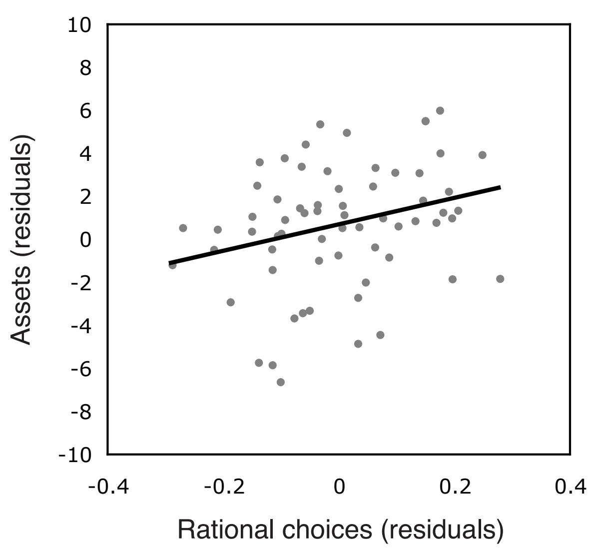
Supplementary Figure 2. Volume of interest placement.

Spheres were hand-placed bilaterally in four brain regions (MPFC = medial prefrontal cortex, AIns = anterior insula, ACaud = anterior caudate, NAcc = nucleus accumbens) on the anatomical images of individual subjects. Small volumes of interest (6 mm diameter spheres) were used to ensure that equal amounts of and only gray matter were included in each volume across age. The location of all 8 spheres is shown here for 4 sample subjects of various ages.

Supplementary Table 2. Investment task optimal choices and real world assets

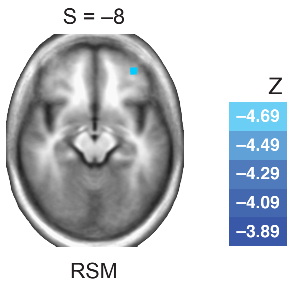
Relationship between rational choices in the BIAS task and real world assets controlling for liabilities and age. Coefficients are standardized betas. * significant at 5% ** significant at 1%

Estimated assets	Coefficient (t)
Rational choices in task	0.256
	(2.66) **
Estimated liabilities	0.214
	(2.35) *
Age	0.703
	(5.74) **
Constant	
	(0.41)
Observations	64
R-sq	0.453



Supplementary Figure 3. Investment task optimal choices and real world assets

A partial plot (controlling for age and liabilities) reveals that the proportion of rational choices in the experimental BIAS task was significantly associated with the accrual of financial assets outside of the laboratory.



Supplementary Figure 4. Outcome-related neural activity and risk-seeking mistakes
Individuals with reduced sensitivity to outcomes in the middle frontal gyrus made more risk-seeking mistakes. However, outcome-elicited activity in this region did not vary with age, so the role of this region in age-related investment mistakes was not further explored or discussed. Anatomical underlay is an average of all subjects' spatially normalized structural scans.

Supplementary Table 3. Outcome-related neural activity and risk-seeking mistakes
Relationship between outcome sensitivity and risk-seeking mistakes (controlling for age)
Z > 3.888, p < .0001, 8 voxel cluster threshold

Region	R	A	S	Z	Voxels
L Middle Frontal Gyrus	–36	50	–8	–4.600	56
L Inferior Frontal Gyrus	–44	8	18	–3.908	8
L Superior Temporal Gyrus	–44	–2	–12	4.173	12
L Inferior Parietal Lobule	–32	–36	38	–4.054	16
L Posterior Cingulate / Precuneus	–10	–44	34	–4.183	16
L Posterior Cingulate / Precuneus	8	–56	30	–4.083	8
R Precuneus	12	–56	34	–3.918	8
R Cuneus	8	–78	18	–3.928	8

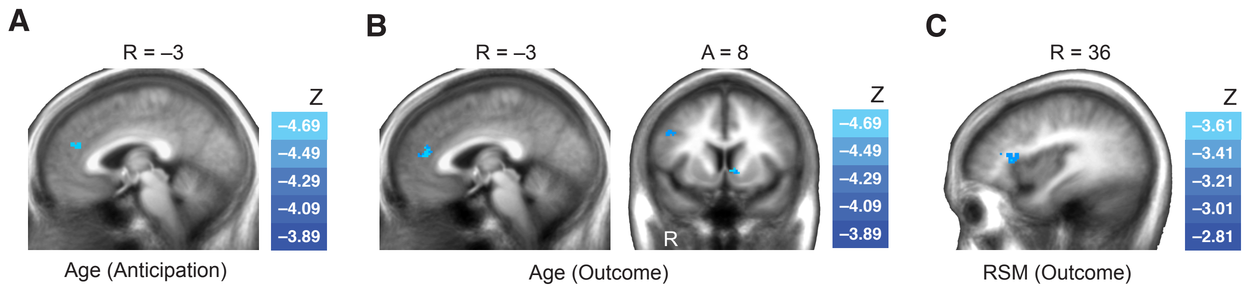
Supplementary Table 4. Logit prediction of risky (stock) choices.

Stock Choice$_t$	Coefficient (Z)
L NAcc$_t^{ANT}$	0.250
	(2.56) *
L MPFC$_t^{ANT}$	–0.158
	(–1.72)
L Insula$_t^{ANT}$	0.240
	(1.42)
Relative Earnings$_{t-1}$	–0.036
	(–5.64) **
Outcome$_{t-1}$	–0.050
	(–4.54) **
Uncertainty$_{t-1}$	–1.69
	(–4.87) **
Cumulative Earnings$_{t-1}$	–0.001
	(–0.67)
Age	0.004
	(0.52)
Constant	0.734
	(2.41) *
Observations	4808
Pseudo R-sq	0.0334

* $p < .05$

** $p < .01$

Robust standard errors clustered within subject.



Supplementary Figure 5. Functional connectivity with the NAcc

Functional connectivity between the right NAcc and the rostral anterior cingulate was reduced with age during both (A) anticipation and (B) outcome. Functional connectivity between the right and left NAcc also decreased with age in the outcome phase (B). (C) Individuals with reduced functional connectivity between the NAcc and inferior frontal gyrus / insula in response to outcomes made more risk-seeking mistakes. However, functional connectivity between these regions did not vary with age, so could not account for age-related increases in risk-seeking mistakes. Anatomical underlay is an average of all subjects' spatially normalized structural scans.

Supplementary Table 5. Functional connectivity with the NAcc

A. Age-related decreases in connectivity with the R NAcc during anticipation (Z > 3.888, p < .0001, 8 voxel cluster threshold)

Region	R	A	S	Z	Voxels
L Anterior Cingulate	–3	39	20	–4.768	21

B. Age-related decreases in connectivity with the R NAcc during outcome (Z > 3.888, p < .0001, 8 voxel cluster threshold)

Region	R	A	S	Z	Voxels
L Medial Frontal Gyrus	-11	62	9	–4.880	43
R Middle Frontal Gyrus	25	59	13	–4.483	16
R Middle Frontal Gyrus	24	52	23	–4.428	21
L Anterior Cingulate	–3	41	16	–5.294	68
R Middle Frontal Gyrus	36	41	16	–4.371	63
R Middle Frontal Gyrus	50	24	27	–4.845	140
R Middle Frontal Gyrus	50	11	32	–4.325	19
L Nucleus Accumbens / Caudate	–8	8	2	–4.776	28

C. Relationship between connectivity with the R NAcc during outcome and risk-seeking mistakes (controlling for age) (Z > 2.808, p < .005, 36 voxel cluster threshold)

Region	R	A	S	Z	Voxels
R Inferior Frontal Gyrus / Anterior Insula	36	24	9	–3.676	57
R Declive	13	–62	–15	–3.772	307
L Pyramis	–3	–64	–24	–3.463	94

Controlling for self-reported investment experience

Although investment experience should increase with age and thus older adults should know better than younger adults that stocks are risky, we did include a crude self-report measure of investment experience:

> "How much experience do you have with investing? (check one)
>
> ___ I have had a savings account, but no other investments.
> ___ I have had investments other than a savings account (e.g., stocks, bonds, or mutual funds), but I do not tend to make my own decisions about those investments.
> ___ I actively make decisions about investing my money (e.g., in stocks, bonds, and other types of investments)."

This self-report measure was positively correlated with age ($r = .26$, $p = .03$). Investment experience was not correlated with overall rational choices, but was correlated with rational stock choices ($r = .33$, $p = .008$) controlling for age. However, investment experience was not significantly associated with the primary behavioral outcome of interest, risk-seeking mistakes, ($r = .02$, $p = .88$) controlling for age. This measure of investment experience does not influence the effects of age on suboptimal choices in general or risk-seeking mistakes when included in model. Thus, it does not appear that differential investment experience can account for the age-related effects.