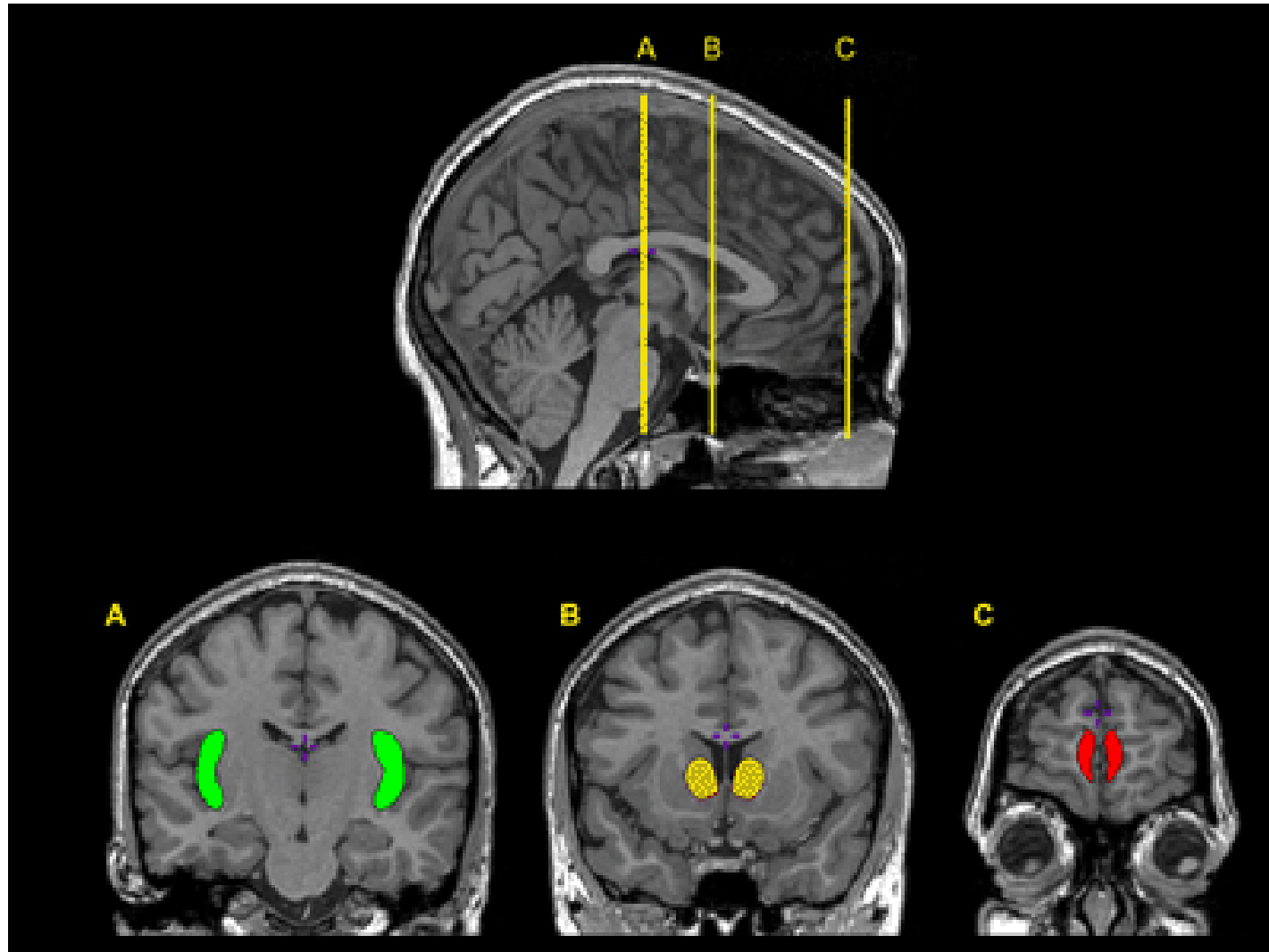


**Neuroeconomics:
How do financial decisions come about?**

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October 2011

The emotional brain is a key player in decision making



Anterior
insula

Nucleus
accumbens

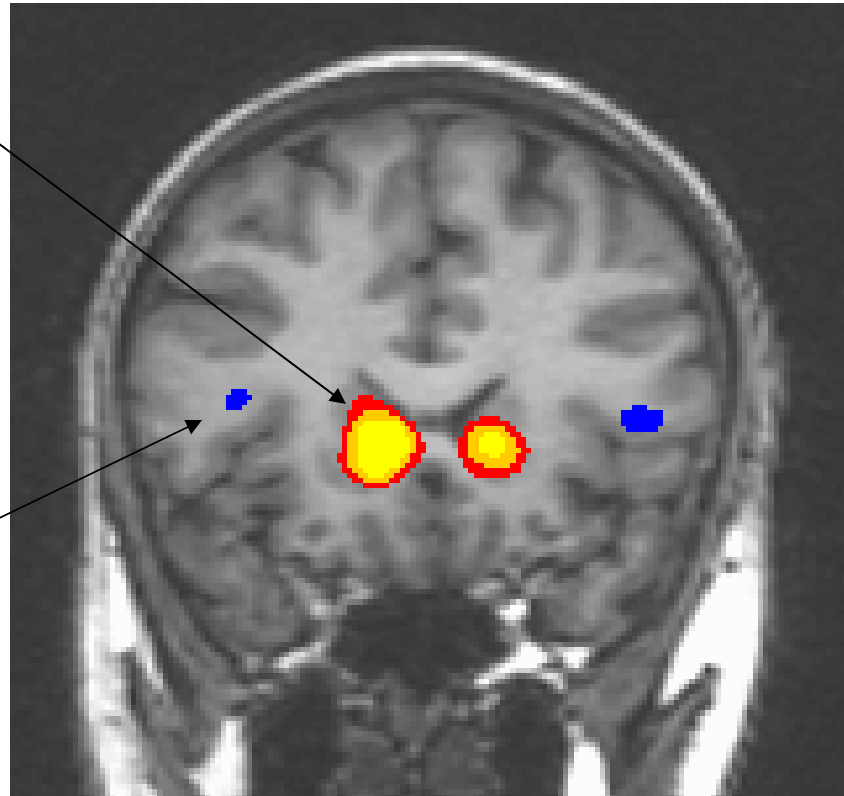
MPFC

Nucleus accumbens

- works through Dopamine
- important for approach behaviors
- activation corresponds to state of excitement

Anterior insula

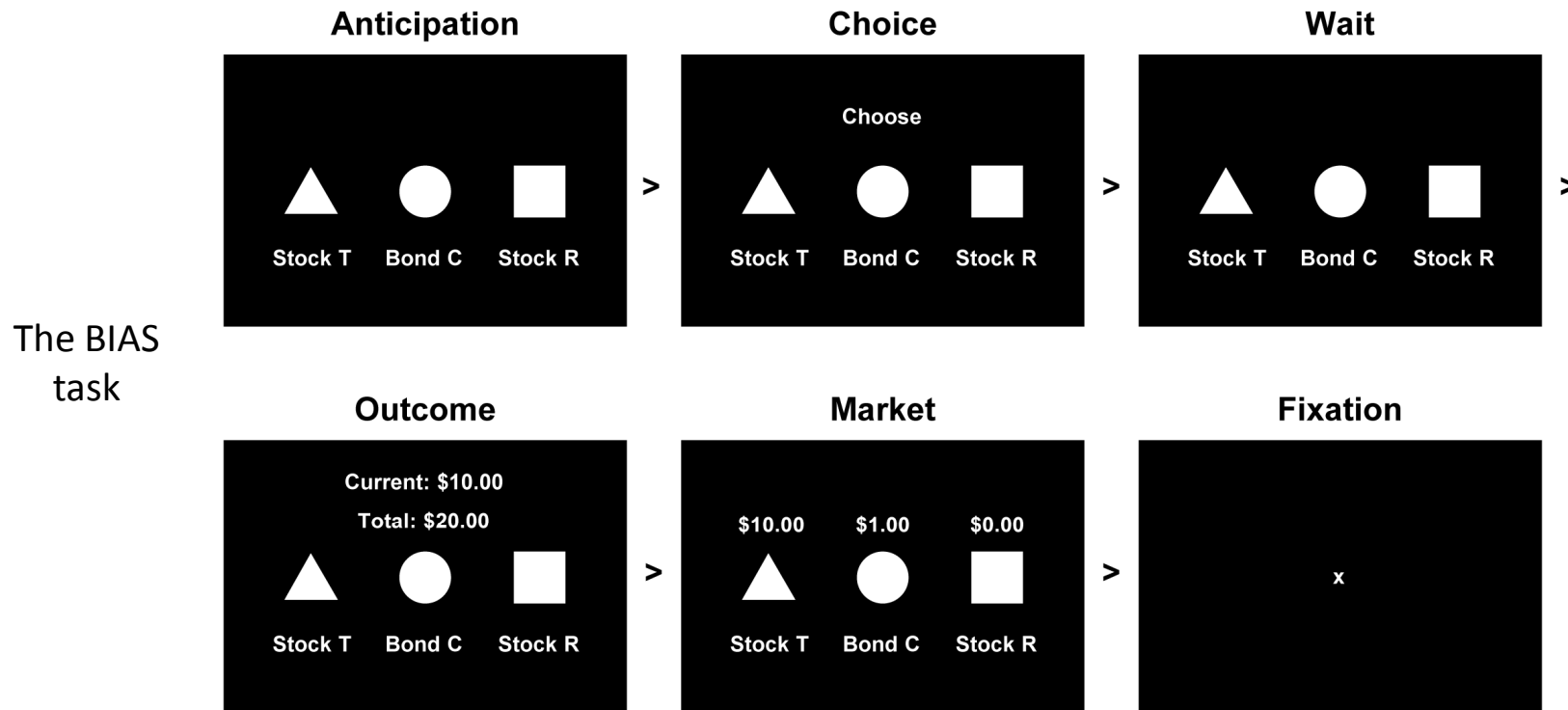
- works partly through Serotonin
- important for avoidance behaviors
- activation corresponds to state of anxiety



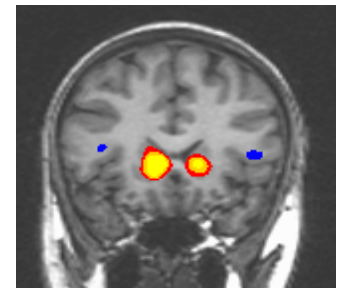
fMRI brain maps:
colors indicate sign and
significance of correlation
between activation and
variables of interest

Kuhnen and Knutson (*Neuron*, 2005)

- Are brain areas related to affect involved in financial decision making?
 - Nucleus accumbens (NAcc) : activates during anticipation of gain or rewarding outcomes (Knutson et al. (2001), Breiter et al. (2001))
 - Anterior insula: activates during anticipation of loss or aversive outcome (Paulus et al. (2003), Simmons et al. (2004))



- Results:
 - NAcc activation precedes **risk-seeking** choices and mistakes
 - Anterior insula activation precedes **risk-averse** choices and mistakes



Experimental Design

- fMRI Brain Scanning: 1.5 T, 4 mm³ spatial resolution, 2 sec temporal resolution
- Subjects: 19 Stanford Ph.D. students (Finance and Humanities)
- Choice: one of two stocks or a bond each trial
- Goal: maximize earnings
- Payment: 10% of task earnings + \$20/hour.

- Task includes 20 blocks of 10 trials each
- At the beginning of each block, stocks are randomly assigned as “good” or “bad” (first order stochastic dominance)
- Participants know one stock dominant, but don’t know which.

Good stock:

\$10 w/ prob. 50%
-\$10 w/ prob. 25%
\$0 w/ prob. 25%

Bad stock:

\$10 w/ prob. 25%
-\$10 w/ prob. 50%
\$0 w/ prob. 25%

Bond: \$1 w/ prob. 100%

Encoding of outcomes in the brain

Dependent variable	$INAcc_t^{OUT}$	$linsul_t^{OUT}$	$IMPFC_t^{OUT}$
	Coef.	Coef.	Coef.
-10.00_t	-0.0138 (0.56)	0.0224 (1.21)	-0.0076 (0.26)
$+10.00_t$	0.0838 (3.85)***	0.0013 (0.08)	0.1408 (5.23)***
$Uncertainty_t$	-0.0322 (0.49)	0.0063 (0.14)	-0.1090 (1.59)
$CumEarnings_{t-1}$	-0.0000 (0.16)	0.0001 (1.07)	0.0001 (1.30)
$Constant$	0.1083 (2.27)**	0.0992 (2.57)**	-0.0219 (0.27)
Observations	2036	2036	2036
R-sq	0.0581	0.0518	0.0434

Dependent variable	$INAcc_t^{MKT}$	$linsul_t^{MKT}$	$IMPFC_t^{MKT}$
	Coef.	Coef.	Coef.
-20.00_t	-0.0159 (0.46)	0.0551 (1.87)*	0.0295 (0.64)
-10.00_t	0.0227 (0.80)	0.0388 (1.75)*	-0.0519 (1.63)
$+10.00_t$	0.0525 (2.23)**	-0.0174 (0.83)	0.0732 (2.43)**
$+20.00_t$	0.0531 (2.10)**	-0.0619 (2.78)***	0.0918 (2.83)***
$Outcome_t$	0.0015 (1.08)	0.0021 (1.80)*	-0.0009 (0.51)
$Uncertainty_t$	0.0619 (1.04)	-0.0898 (1.70)*	0.0513 (0.71)
$CumEarnings_{t-1}$	0.0001 (0.85)	0.0001 (1.76)*	0.0000 (0.15)
$Constant$	-0.1496 (3.94)***	-0.1505 (3.82)***	-0.2006 (2.42)**
Observations	2036	2036	2036
R-sq	0.0237	0.0314	0.0347

Brain activation predicts risky vs. riskless choice

	<i>Previous choice was a stock</i>	<i>Previous choice was bond</i>	<i>All data</i>
<i>StockChoice_t</i>	Coef	Coef	Coef
<i>INAcc_t^{ANT}</i>	-0.0498 (0.24)	0.5889 (3.21)***	0.3192 (2.70)***
<i>IMPFC_t^{ANT}</i>	-0.0461 (0.26)	-0.0222 (0.15)	-0.0137 (0.14)
<i>linsula_t^{ANT}</i>	-0.7875 (3.04)***	0.1910 (0.89)	-0.2359 (1.69)*
<i>RelEarnings_{t-1}</i>	-0.0550 (5.18)***	0.0447 (4.08)***	-0.0360 (6.65)***
<i>Outcome_{t-1}</i>	-0.0253 (1.88)*		-0.0452 (4.65)***
<i>Uncertainty_t</i>	-4.7256 (7.68)***	-8.8818 (12.89)***	-8.1441 (21.42)***
<i>CumEarnings_{t-1}</i>	-0.0036 (3.43)***	-0.0017 (1.99)**	-0.0031 (5.51)***
<i>Constant</i>	2.7542 (7.37)***	1.8624 (5.30)***	2.7986 (12.33)***
Observations	1578	1595	3367
Pseudo R-sq	0.27	0.31	0.33

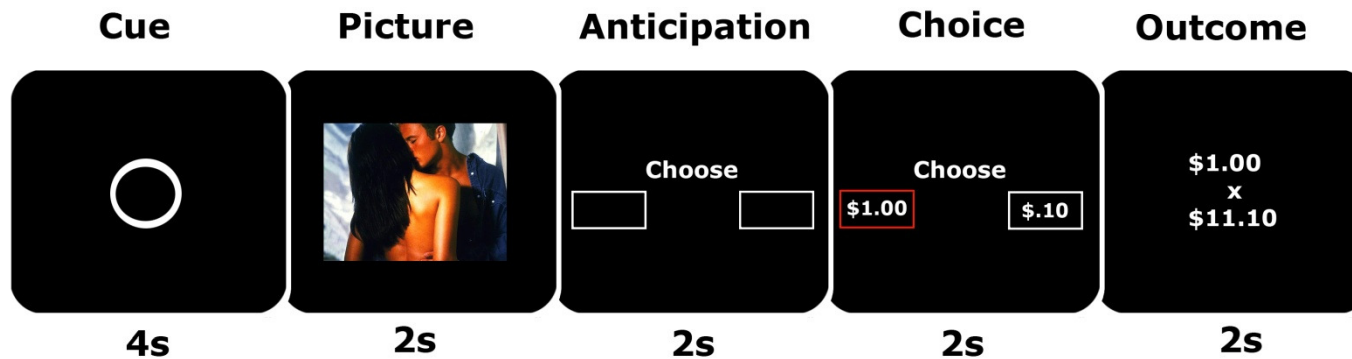
Samanez-Larkin, Kuhnen, Yoo and Knutson (*J. Neuroscience*, 2010)

- How does activation in brain emotional areas related to financial choice across the life span?
- In BIAS task, older adults made more suboptimal choices than younger adults when choosing stocks
- This age-related effect was mediated by temporal variability in nucleus accumbens activity
 - suggests a novel neural mechanism by which aging may disrupt rational financial choice.

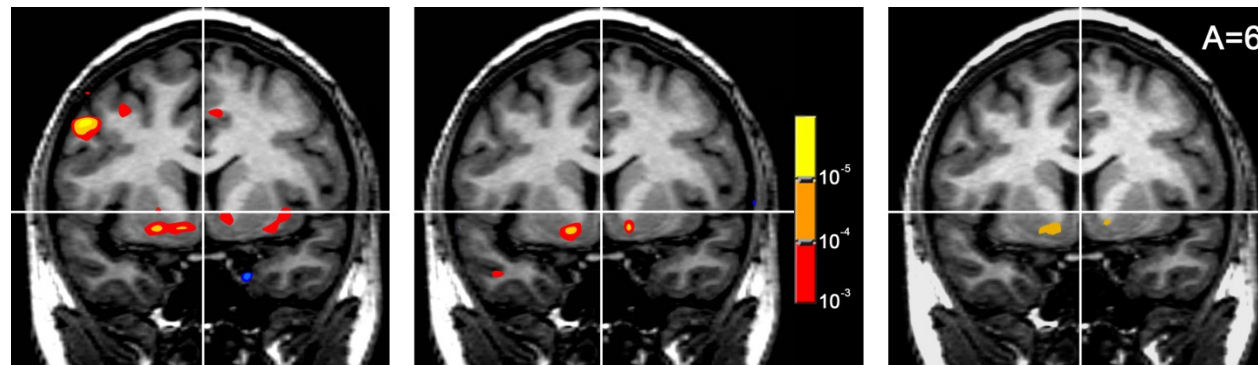
Knutson, Wimmer, Kuhnen and Winkielman (*NeuroReport*, 2008)

- Does brain activation in NAcc/Insula **reflect** the decision to go for or avoid risk, or does it **cause** the decision? Can we exogenously change activation in these areas and modify risk taking behavior?

Each trial : Choose between high- and low-variance lotteries, same E[V]



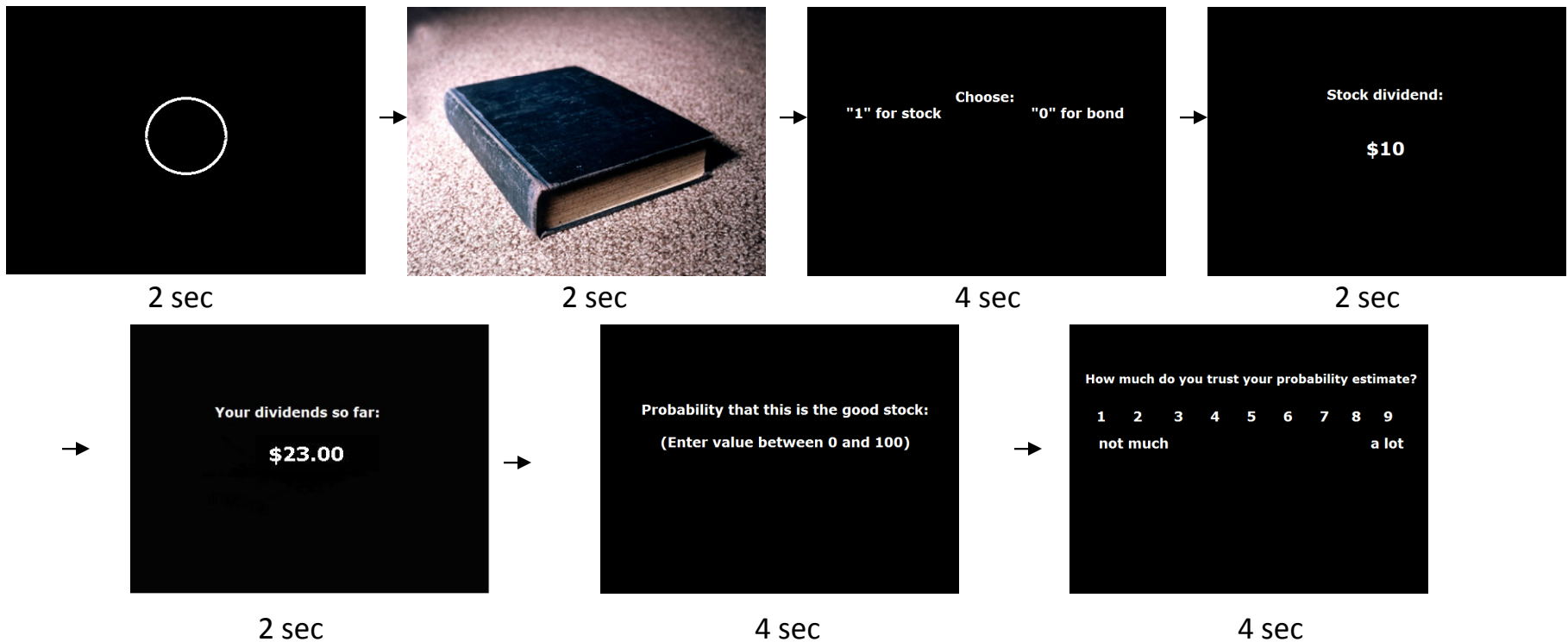
- Anticipation of viewing highly rewarding stimuli promoted subsequent financial risk taking.
- The effect was partially mediated by increased Nucleus Accumbens activation.



Brain activation associated with viewing positive vs. negative stimuli (left), with anticipation of shifting to the high risk option versus shifting to the low risk option (middle), and with their conjunction.

Kuhnen and Knutson (*JFQA*, 2011)

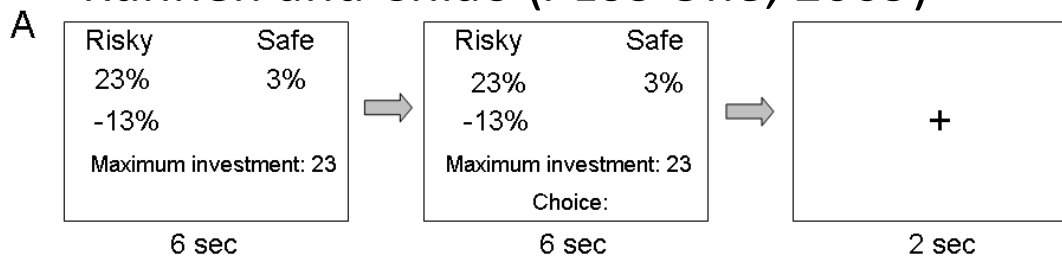
- Does affect influence risk preferences, beliefs, or both?
- Computer randomizes the type of stock the subject is faced with, every 5th trial (90/subject)
 - If Good stock:**
 - \$10 w/ prob. 75%
 - \$10 w/ prob. 25%
 - If Bad stock:**
 - \$10 w/ prob. 25%
 - \$10 w/ prob. 75%
 - Bond:** \$3 w/ prob. 100%
- At the beginning of each trial a picture is presented: (a) positive and arousing, (b) negative and arousing, or (c) neutral



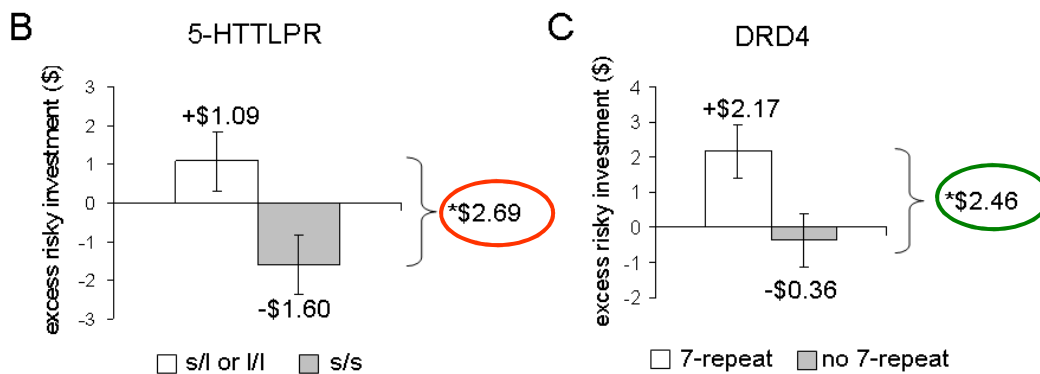
- Positive and arousing emotions (excitement) lead to riskier choices, while negative and arousing emotions (anxiety) lead to more risk averse choices
- Positive arousal increases the subjects' confidence in their ability to evaluate risky investments
- Beliefs about these investments are updated in way consistent with the self-preservation motive of maintaining positive affect and avoiding negative affect
- Subjects do not fully incorporate news that contradict their prior choices, and thus form incorrect posterior beliefs
- Conservatism when updating moderate priors, overreaction when news is against extreme priors

Kuhnen and Chiao (*PLoS One*, 2009)

Trial sequence



Risk in excess of benchmark model



Gene effect size:

25%-28% of the average risky investment

Benchmark investment model

Dependent Variable:	<i>Amount invested in risky asset</i>
	Coefficient/t-stat
<i>Risky Asset Expected Return</i>	42.89 (9.20)***
<i>Risky Asset Std. Dev. of Return</i>	-3.92 (-2.55)**
<i>Safe Asset Return</i>	-70.01 (-7.81)***
<i>Available funds</i>	0.39 (7.34)***
<i>Trial number</i>	-0.01 (-1.42)
<i>Constant</i>	-2.66 (-1.64)
Adj. R2	0.13
Observations	5987

** p < 0.05, *** p < 0.01

Kuhnen, Samanez-Larking and Knutson (*WP*, 2011)

- What is the mechanism driving the correlation between particular gene variants and financial risk taking?
- Focus on the role of the serotonin transporter gene (5HTTLPR) on financial choice
- Short allele (SS) carriers do not differ from others with respect to cognitive skills, education, or wealth, but they have higher levels of neuroticism
- Genetically-driven negative emotional reactions induce the short gene carriers to avoid risky and complex financial choices

	%Stock Allocation	%Cash Allocation	Involvement in Finances	Number of credit lines	FICO score
<i>fivehttlpr == SL</i>	-9.18 (-0.91)	3.12 (0.36)	-0.65 (-3.16)***	-13.43 (-2.10)**	47.16 (1.21)
<i>fivehttlpr == SS</i>	-23.84 (-2.86)***	25.60 (3.04)***	-0.45 (-2.15)**	-12.63 (-1.81)*	93.25 (1.90)*
<i>Age</i>	-0.42 (-1.92)*	0.34 (1.25)	0.02 (4.51)***	-0.08 (-0.45)	2.40 (3.23)***
<i>Male</i>	6.53 (0.85)	-6.70 (-0.89)	0.10 (0.57)	4.48 (1.05)	-10.49 (-0.39)
<i>Constant</i>	70.47 (4.75)***	5.80 (0.35)	1.46 (4.20)***	31.14 (2.65)**	575.02 (7.99)***
<i>R²</i>	0.12	0.14	0.33	0.28	0.38
Observations	60	60	60	31	31

- Genetically-driven negative emotional reactions lead SS carriers to avoid risky & complex financial choices

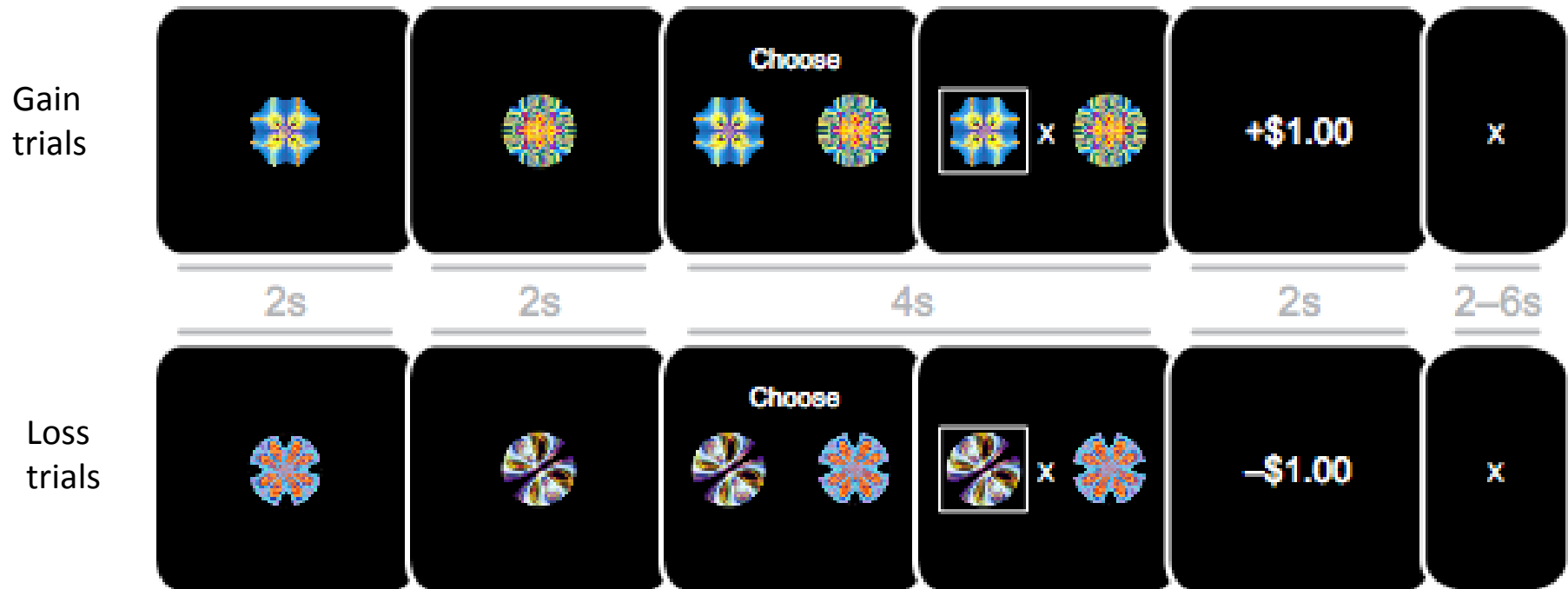
	Neuroticism	%Stock Allocation	%Cash Allocation	Involvement in Finances	Number of credit lines	FICO score
<i>fivehttlpr == SL</i>	4.18 (1.71)*					
<i>fivehttlpr == SS</i>	7.40 (3.01)***					
<i>Neuroticism^{Predicted}</i>		-3.46 (-2.96)***	3.76 (3.03)***	-0.06 (-2.09)**	-1.88 (-1.82)*	12.90 (1.92)*
<i>Neuroticism^{Residual}</i>		-0.59 (-1.27)	0.24 (0.46)	-0.03 (-2.13)**	-0.05 (-0.14)	0.95 (0.80)
<i>Age</i>		-0.38 (-1.81)*	0.22 (0.91)	0.02 (3.75)***	-0.18 (-1.14)	2.26 (3.39)***
<i>Male</i>		3.40 (0.44)	-6.53 (-0.83)	-0.11 (-0.70)	2.96 (0.57)	-4.02 (-0.15)
<i>Constant</i>	22.67 (13.34)***	150.96 (4.04)***	-77.83 (-1.97)**	3.04 (3.50)***	78.78 (2.31)**	285.08 (1.30)
<i>R²</i>	0.09	0.14	0.12	0.36	0.24	0.39
Observations	60	60	60	60	31	31

- Suggestive evidence from fMRI data

	Gain condition		Loss condition	
	Nucleus Accumbens before choice	Anterior Insula before choice	Nucleus Accumbens before choice	Anterior Insula before choice
<i>fivehttlpr == SL</i>	-0.06 (-1.56)	-0.03 (-1.07)	-0.03 (-1.07)	0.06 (1.31)
<i>fivehttlpr == SS</i>	-0.09 (-3.94)***	-0.00 (-0.17)	-0.00 (-0.17)	0.07 (1.98)**
<i>Age</i>	-0.00 (-0.90)	0.00 (0.39)	0.00 (0.39)	-0.00 (-0.10)
<i>Male</i>	-0.10 (-2.41)**	0.02 (0.99)	0.02 (0.99)	-0.02 (-0.68)
<i>Constant</i>	0.16 (2.19)**	0.02 (0.41)	0.02 (0.41)	-0.04 (-0.69)
<i>R²</i>	0.019	0.002	0.002	0.008
Observations	600	600	600	600

Knutson, Samanez-Larkin and Kuhnen (*PLoS One*, 2011)

- How does learning impact real-life financial outcomes?
- Monetary Incentive Learning (MIL) Task
 - in gain pairs, better cue had a higher probability of yielding gains (66% +\$1.00 and 33% \$0.00) than worse cue (33% +1.00 and 66% \$0.00)
 - in loss pairs, better cue had a higher probability of yielding zero (66% \$0.00 and 33% –\$1.00) than worse cue (33% \$0.00 and 66% –\$1.00)



- Gain learning predicts ↑ assets, loss learning predicts ↓ debt

	<i>Assets</i>	<i>Assets</i>	<i>Debt</i>	<i>Debt</i>
<i>Gain correct choices</i>	3.30 2.85**	2.06 2.48*	1.74 1.05	1.06 0.62
<i>Loss correct choices</i>	-2.66 -1.30	-2.30 -1.44	-5.92 -2.14*	-8.57 -2.84**
<i>Debt</i>	0.10 1.25	0.06 0.92		
<i>Assets</i>			0.19 1.25	0.23 0.92
<i>Income</i>		0.60 4.67**		0.34 1.19
<i>Working memory</i>		0.06 0.52		-0.10 -0.45
<i>Cognitive flexibility</i>		0.01 0.23		-0.01 -0.36
<i>Numeracy</i>		0.27 1.17		0.39 0.83
<i>Age</i>		0.14 6.30***		-0.07 -1.29
<i>Education</i>		0.05 0.35		0.33 1.28
<i>Male</i>		-0.33 -0.57		0.97 0.86
<i>Constant</i>	11.97 7.22***	-2.05 -0.66	7.80 2.79***	3.15 0.51
<i>Ethnicity FEs</i>	Yes	Yes	Yes	Yes
Adjusted R ²	0.11	0.62	0.07	0.17
Observations	82	80	82	80

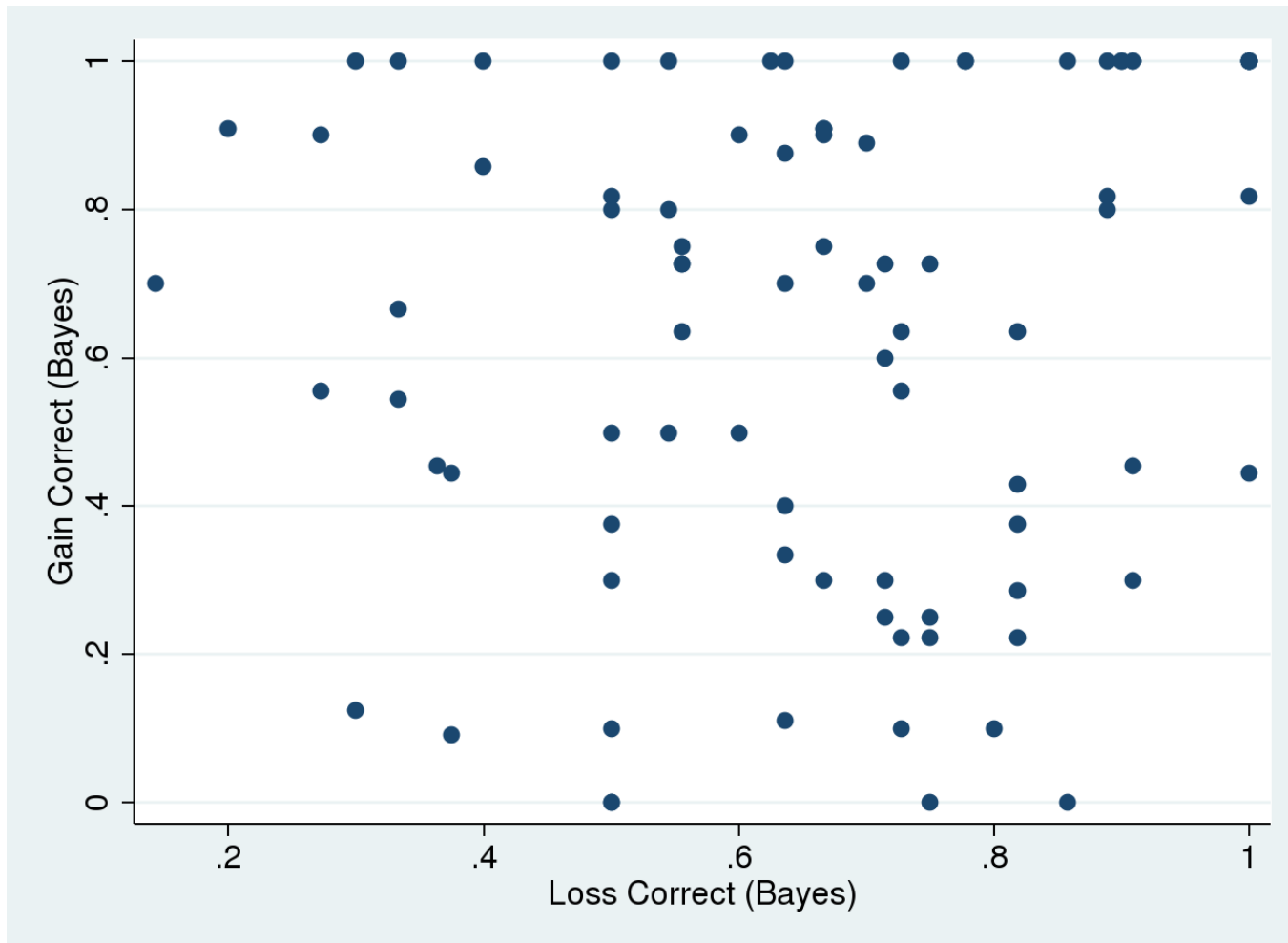
- Sensitivity of MPFC to gain information predicts gain learning and sensitivity of Anterior Insula to loss information predicts loss learning

	<i>GainCorrect</i> (<i>Bayes</i>)	<i>GainCorrect</i> (<i>Bayes</i>)	<i>LossCorrect</i> (<i>Bayes</i>)	<i>LossCorrect</i> (<i>Bayes</i>)
$\beta_{MPFC^{ANT}}_{EVOP_GAIN}$	0.08 (2.34)**	0.07 (1.87)*		
$\beta_{INSULA^{ANT}}_{EVOP_LOSS}$			0.03 (1.30)	0.06 (2.46)**
Constant	0.65 (13.74)***	0.65 (12.17)***	0.69 (19.79)***	0.63 (19.36)***
Adj. R^2	0.11	0.06	0.02	0.12
Observations	39	39	39	39

- Sensitivity to gain information and sensitivity to loss information are not related within person

	$\beta_{MPFC^{ANT}}_{EVOP_GAIN}$	$\beta_{MPFC^{ANT}}_{EVOP_GAIN}$
$\beta_{MPFC^{ANT}}_{EVOP_LOSS}$	-0.01 (-0.13)	
$\beta_{INSULA^{ANT}}_{EVOP_LOSS}$		-0.08 (-0.46)
Constant	0.08 (0.33)	0.07 (0.30)
Adj. R^2	-0.03	-0.02
Observations	39	39

Learning about gains and learning about losses are different within individuals



Kuhnen and Baleanu (*WP*, 2011)

- Is learning from financial information asymmetric in **Gain** vs. **Loss** conditions, or during **Active** vs. **Passive** involvement in financial decisions?
 - **Gain** condition: only positive payoffs possible
 - **Loss** condition: only negative payoffs possible

 - **Active** involvement: judge a risky asset while having to decide to invest in it or not
 - **Passive** involvement: judge a risky asset while not make investment decisions
- Are there genetic correlates of learning and choice performance across these different domains?

- Task: Risky asset can either be good or bad
 - Good stock pays high dividend with 70% probability
 - Bad stock pays high dividend with 30% probability

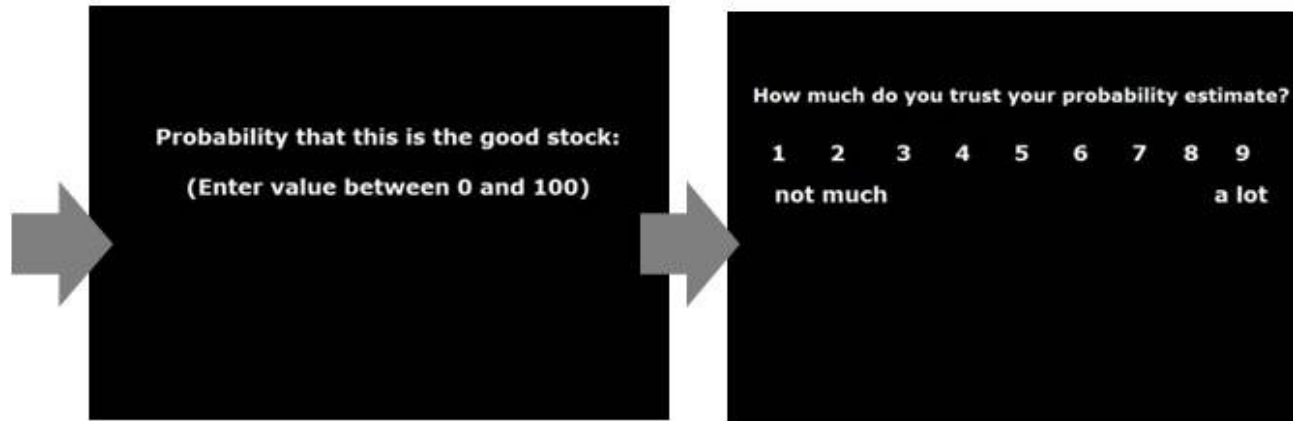
Gain Condition - Active Involvement



4 seconds

2 seconds

2 seconds



5 seconds

4 seconds

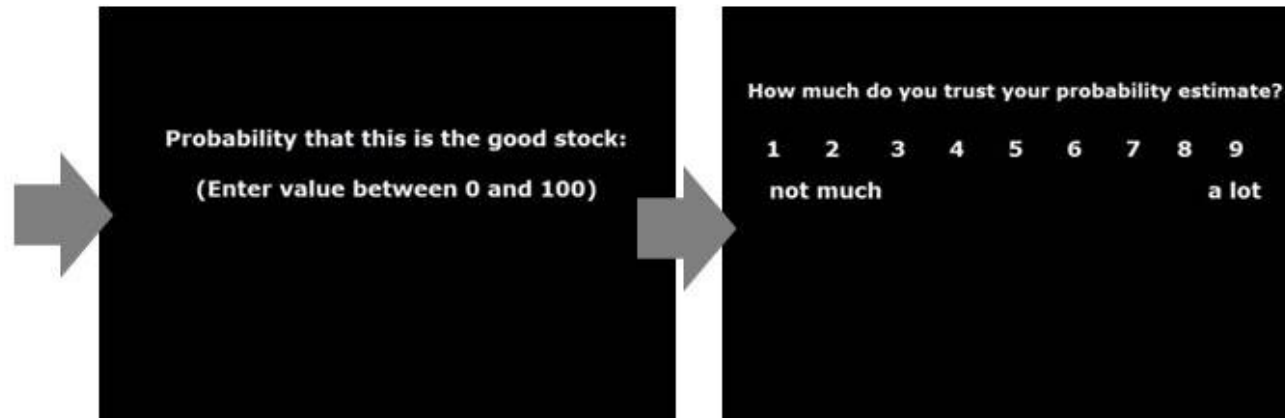
Loss Condition - Active Involvement



4 seconds

2 seconds

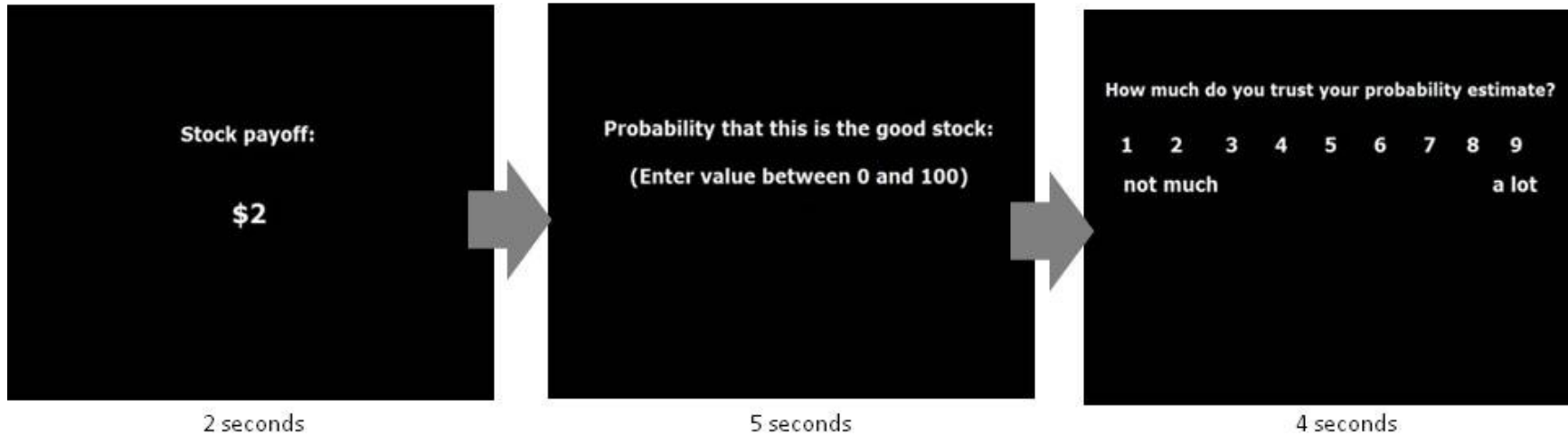
2 seconds



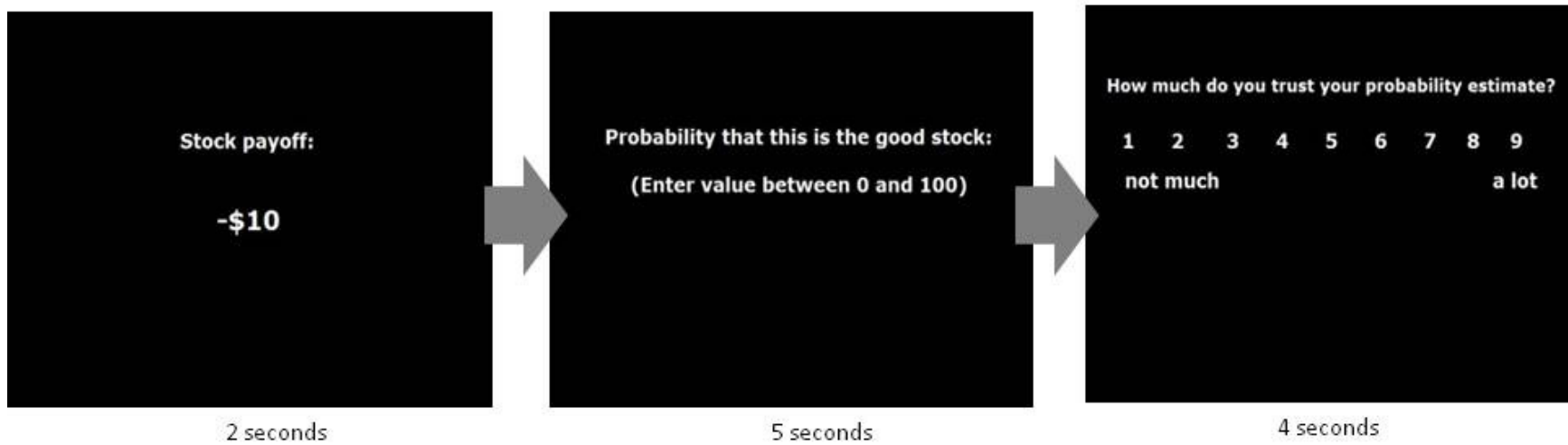
5 seconds

4 seconds

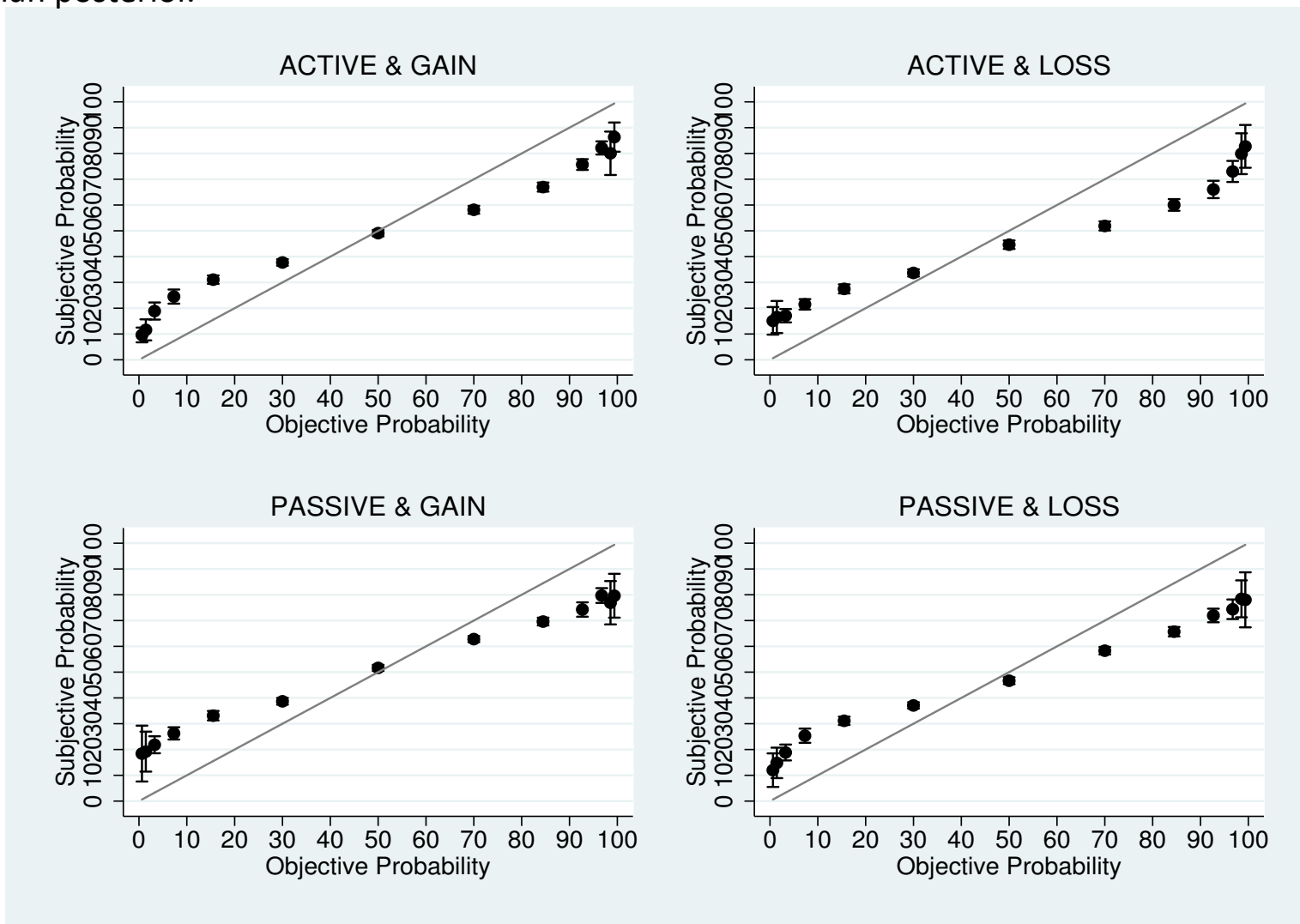
Gain Condition - Passive Involvement

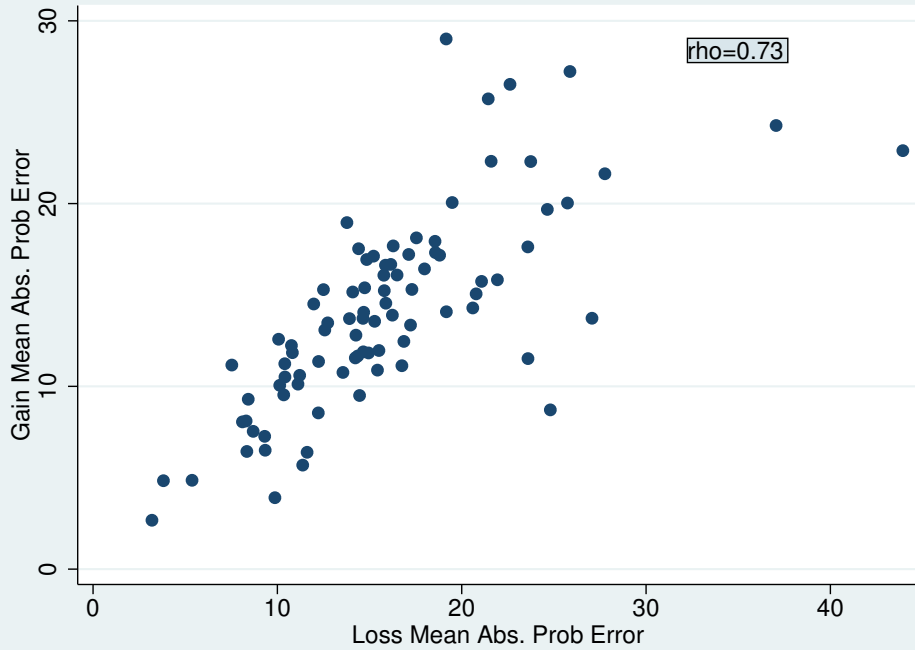


Loss Condition - Passive Involvement



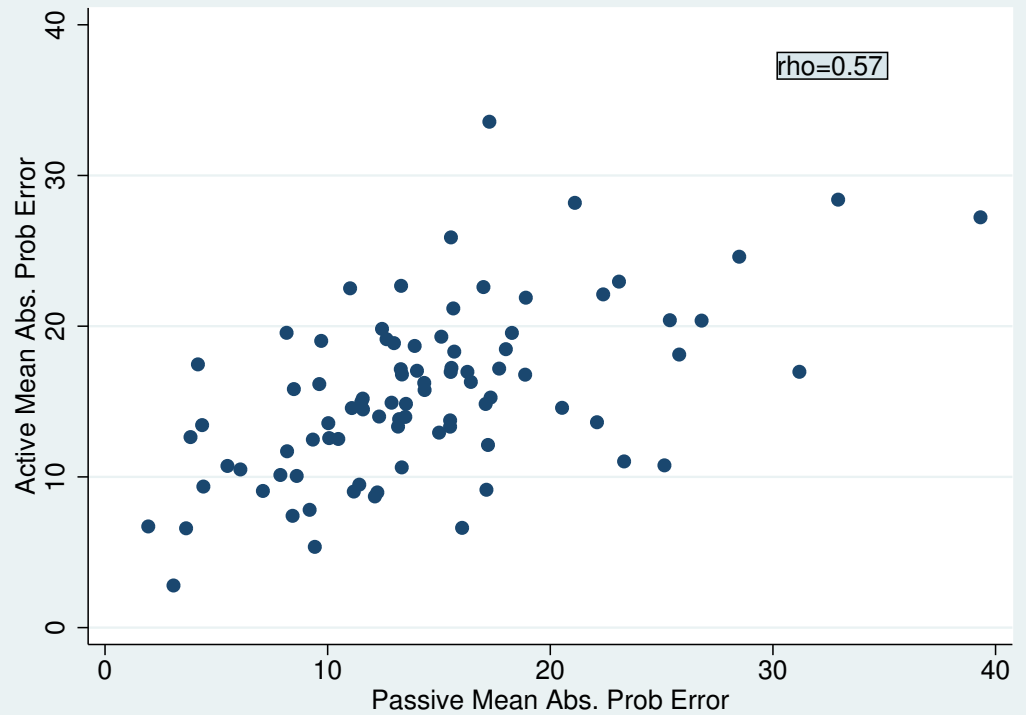
- Errors in subjective probability estimates (measured relative to the objective Bayesian posteriors that the stock was paying from the good distribution) were 2% lower in the Gain condition relative to the Loss condition ($p < 0.001$)
- Difference in probability estimation errors between the Gain and Loss conditions was twice as large in the Active task (2.6%) relative to the Passive task (1.2%), and the effect was strongest (5.5%) for high values of the Bayesian posterior.





Within individual, Gain and Loss learning performance were only partially correlated ($\rho = 0.73, p < 0.001$).

Active and Passive learning performance were also only partially correlated ($\rho = 0.57, p < 0.001$)



- Learning performance better for *COMT Met/Met* genotype

- Choices closer to risk-neutral, Bayesian optimal strategy for *COMT Met/Met*, *MAOA-H*, *DRD4 Exon III* short allele carriers.

Dependent variable	<i>Absolute Probability Error_{it}</i>
<i>COMT Met/Met_i</i>	-2.59 (-2.30)**
<i>MAOA-H_i</i>	-0.30 (-0.29)
<i>5HTTLPR SS_i</i>	0.78 (0.71)
<i>DRD4 Max Num Repeats_i</i>	0.56 (1.31)
<i>DRD2 Taq1A TT_i</i>	0.42 (0.29)
<i>Male_i</i>	-2.16 (-1.85)*
<i>Age_i</i>	0.21 (0.52)
<i>ObjectiveProbability_{it}</i>	0.04 (3.86)***
<i>Loss Condition_{it}</i>	1.88 (3.92)***
<i>Passive Task_{it}</i>	-1.10 (-1.76)*
<i>Constant</i>	9.69 (1.08)
<i>EthnicityFEs</i>	YES
<i>Adj.R²</i>	0.04
<i>Observations</i>	10377

Dependent variable	<i>Optimal choice_{it}</i>
<i>COMT Met/Met_i</i>	0.09 (3.07)***
<i>MAOA-H_i</i>	0.07 (2.20)**
<i>5HTTLPR SS_i</i>	-0.02 (-0.57)
<i>DRD4 Max Num Repeats_i</i>	-0.02 (-1.88)*
<i>DRD2 Taq1A TT_i</i>	0.00 (0.03)
<i>Male_i</i>	0.11 (3.74)***
<i>Age_i</i>	-0.01 (-1.14)
<i>Loss Condition_{it}</i>	0.04 (2.99)***
<i>Ethnicity FEs</i>	YES
<i>PseudoR²</i>	0.07
<i>Observations</i>	3734

Summary of results

- Affect influences choice under risk: brain areas driving behavior in primitive settings (“go for food”, “run away from snakes”) are also involved in financial decision making (Kuhnen and Knutson (*Neuron*, 2005), Samanez-Larkin, Kuhnen, Yoo and Knutson (*J. Neuroscience*, 2010))
- We can exogenously change one’s risk taking behavior by triggering the brain areas that do emotion-processing (Knutson, Wimmer, Kuhnen and Winkielman (*NeuroReport*, 2008))
- Emotions change behavior by changing risk preferences, as well as confidence in beliefs (Kuhnen and Knutson (*JFQA*, 2011))
- Genes that control emotional brain activation generate stable differences in risk taking across people (Kuhnen and Chiao (*PLoS One*, 2009), Kuhnen, Samanez-Larkin and Knutson (WP, 2011))
- Gain and loss learning predict real-life asset and debt (Knutson, Samanez-Larkin and Kuhnen (*PLoS One*, 2011))
- Learning from financial information is different in gain vs. loss conditions, and during passive vs. active involvement (Kuhnen and Baileanu (WP, 2011))

Conclusion

- Neuroeconomics can help us make better sense of economic and financial decisions
- We can write better, more realistic models of behavior
- We can more easily predict individuals' response to changes in policies, market settings or environment cues in general