The Neural Basis of Financial Decision Making

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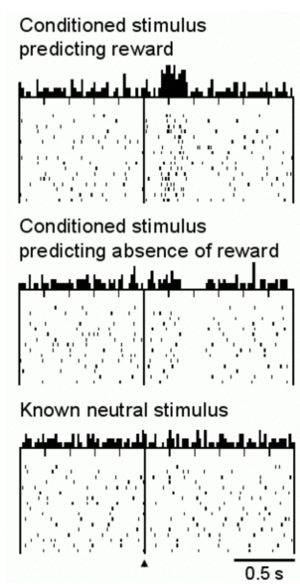
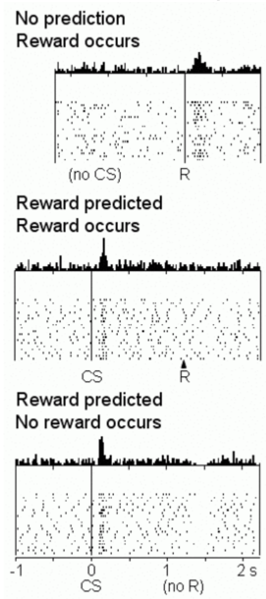
Dopamine predicts rewards



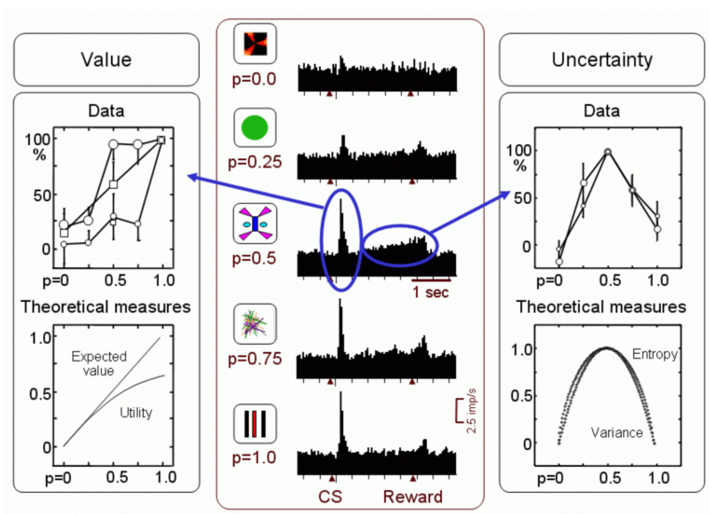
Tobler et al. (2005)

Dopamine encodes reward prediction error



Schultz et al. (1997)

Dopamine codes uncertainty



Fiorillo et. Al (2003)

So far…

- Cognition and emotion together cause behavior
- Emotions provide quick, automatic ways to react: rules of thumb, heuristics
- The limbic system is responsible for emotional reactions
- Dopamine is the key neurotransmitter in the limbic system for reward processing
- It allows us to engage in “approach”-type behaviors
- Other neurotransmitters (e.g.. serotonin) are important for engaging in “avoidance”-type behaviors

- **Do these findings matter at all for financial decision making?**

Some of my own results

- Yes, emotions matter when we make investment choices (as suggested by Lo and Repin (2002))
- Affect does influence choice under risk: old parts of the emotional brain that dictate behavior in **primitive** settings (“go for food”, “run away from snakes”) are also involved in **financial** decision making (Kuhnen and Knutson (2005))
- We can exogenously change one’s risk taking behavior by triggering the brain areas that do emotion-processing (Knutson, Wimmer, Kuhnen and Winkielman (2008))
- Emotions change behavior by changing risk preferences, as well as learning (Kuhnen and Knutson (2008))
- Genes that control emotional brain activation generate stable differences in risk taking across people (Kuhnen and Chiao (2009))

Kuhnen and Knutson (2005)

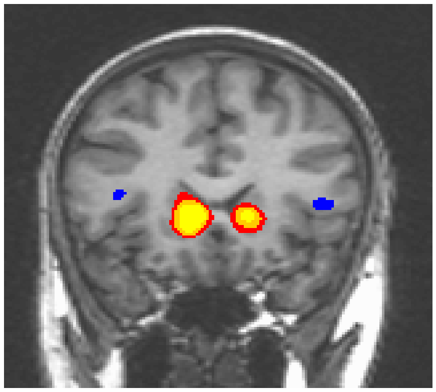
Different neural circuits may generate affect during anticipation of gain versus loss:

- Nucleus accumbens (NAcc) :
  - Activates during anticipation of (monetary) gain (Knutson et al. (2001), Breiter et al. (2001))
- Anterior insula:
  - Activates during (nonmonetary) loss (Paulus et al. (2003), Simmons et al. (2004))
  - Activates during anticipation of pain

Hypotheses:

-NAcc activation precedes risk-seeking choices and mistakes

-Anterior insula activation precedes risk-averse choices and mistakes



Experimental Design

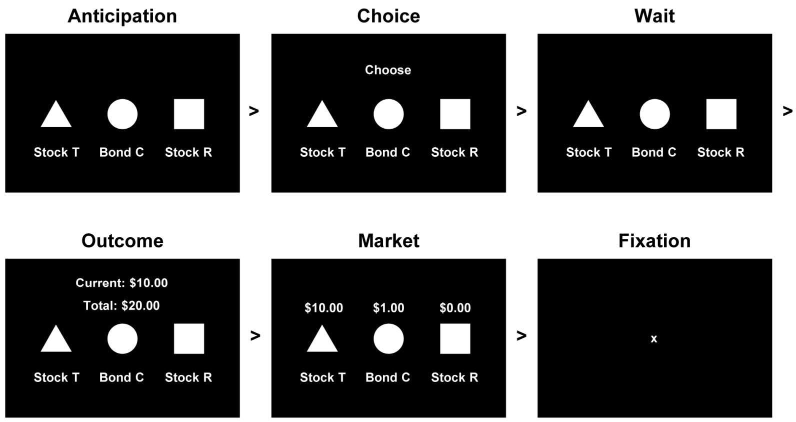
- fMRI Brain Scanning: 1.5 T, 4 mm^3 spatial resolution, 2 sec temporal resolution
- Subjects: 19 Stanford Ph.D. students (Finance and Humanities)
- Choice: one of two stocks or a bond each trial
- Goal: maximize earnings
- Payment: 10% of task earnings + $20/hour.

- 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.

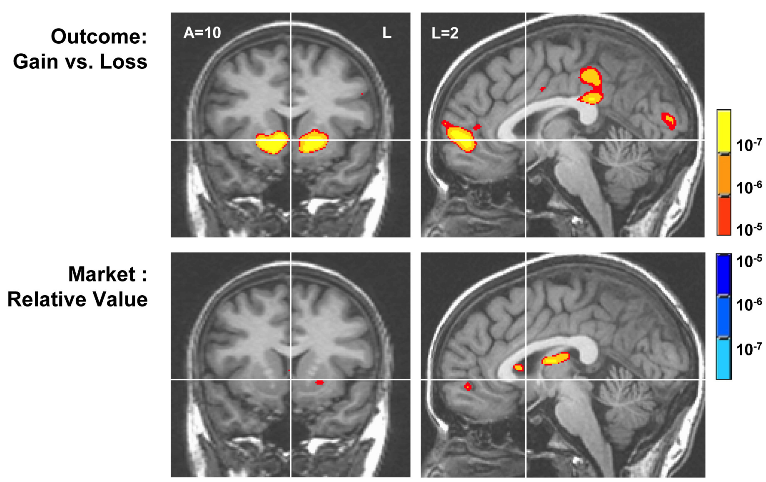
Good stock:	**Bad stock:**
$10 w/ prob. 50%	$10 w/ prob. 25%
-$10 w/ prob. 25%	-$10 w/ prob. 50%
$0 w/ prob. 25%	$0 w/ prob. 25%

Bond: $1 w/ prob. 100%

Trial structure



Results: Localization



Encoding of outcomes in the brain

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

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

Brain activation predicts risky vs. riskless choice

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

Results of Kuhnen and Knutson (2005)

- Activation in the Nucleus Accumbens is a positive predictor of choosing a risky asset
- Activation in the Anterior Insula is a positive predictor of choosing the riskless asset
- Excessive activation in these areas correlates with making risk-seeking and risk-averse mistakes (deviations from optimal choice of a risk neutral, rational agent)

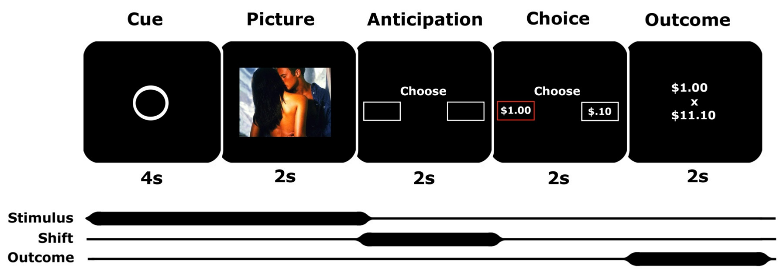
Questions raised by Kuhnen and Knutson (2005)

- Direction of causality: Does brain activation in NAcc/Insula **reflect** the decision to go for or avoid risk, or does it **cause** the decision?
  - investigated in Knutson, Wimmer, Kuhnen and Winkielman (2008)
- Channels: Does affect change decisions under risk by changing **beliefs**, **preferences**, or both, in a systematic way?
  - investigated in Kuhnen and Knutson (2008)
- Genetics: Do genes that regulate emotional brain cause individual differences in risk taking?
  - investigated in Kuhnen and Chiao (2009)

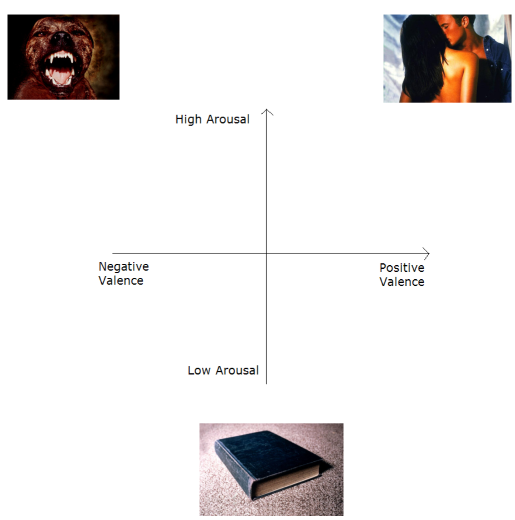
Knutson, Wimmer, Kuhnen and Winkielman (2008)

- Direction of causality: 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?

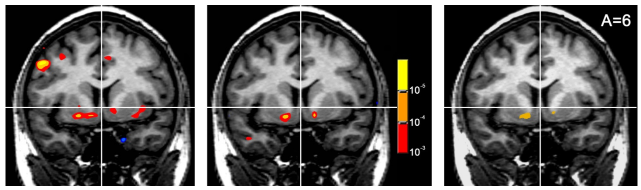
Trial structure (15 subjects, 54 trials/subject)
Choose between high- and low-variance
lotteries, same E[V]



Visual Stimuli in Valence X Arousal Space



•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.

Logistic regressions predicting shifts to high risk lottery

	Stimulus	Brain	Combined
Constant	0.97	1.47	1.42
	0.98 (1.010)	1.50 (1.02)	1.46 (1.029)
Cumulative earnings	0.11	0.25	0.05
	0.01 (0.075)	0.02 (0.075)	0.00 (0.075)
Preceding outcome	-7.40***	-7.75***	-7.54***
	-2.01 (0.271)	-2.19 (0.283)	-2.14 (0.284)
Positive stimulus	2.00*		1.75
	0.57 (0.283)		0.50 (0.286)
NAcc (bilateral)		2.74***	2.59**
		1.14 (0.416)	1.09 (0.419)
Insula (right)		-1.15	-1.03
		-0.44 (0.378)	-0.39 (0.378)
Number of obs.	315	315	315
Pseudo-R^2	0.169	0.178	0.186

Genetic determinants of financial risk taking (Kuhnen and Chiao (2009))

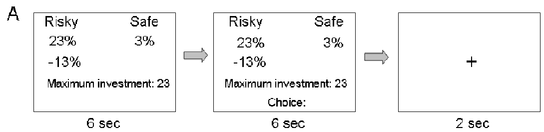
- Twin design studies: genetic effects account for 20% variation in risk taking in experimental lottery choices (Cesarini et al. (2009) and between 35%-54% of the liability for developing symptoms of pathological gambling (Eisen et al. (1998))
- Identification of specific genes underlying financial risk preferences has remained elusive
- Prior research suggests two genes that may regulate risk taking
  - the serotonin transporter polymorphism (5-HTTLPR)
  - the dopamine D4 receptor (DRD4) exon III polymorphism
- The 5-HTTLPR consists of a 44-base pair insertion or deletion, generating either a long (l) or a short (s) allele. The short variant of the polymorphism is associated with higher scores on neuroticism and harm avoidance (Lesch et al. (1996))
- The dopamine D4 receptor (DRD4) exon III polymorphism has been linked to novelty seeking and pathological gambling. Individuals with the 7-repeat allele have higher novelty seeking scores than those with other DRD4 variants (Ebstein et al. (1996)) and are more likely to be pathological gamblers (De Castro et al. (1997))

Genetic determinants of financial risk taking (Kuhnen and Chiao (2009))

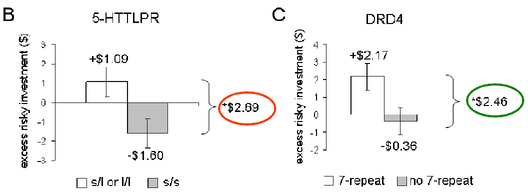
- 65 subjects, 26 male
- 96 investment decisions: allocate $$$ to risky asset and riskless asset
- Risky asset had two possible returns, probabilities were known
- Riskless asset: known return
- Average pay: $25, based on portfolio performance

- 21 carriers homozygous for the s allele and 44 carriers with one or two copies of the l allele of the 5-HTTLPR polymorphism
- 15 carriers of the 7-repeat allele and 50 non-carriers of 7-repeat allele variant of DRD4.

Trial sequence



Risk in excess of benchmark model



Gene effect size:

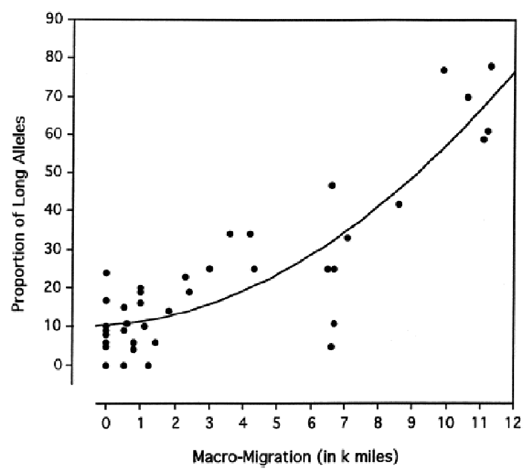
25%-28% of the average risky investment

Benchmark investment model

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

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

Evolutionary argument for DRD4



Chen et al. (1999): Population migration and the variation of dopamine D4 receptor (DRD4) allele frequencies around the globe