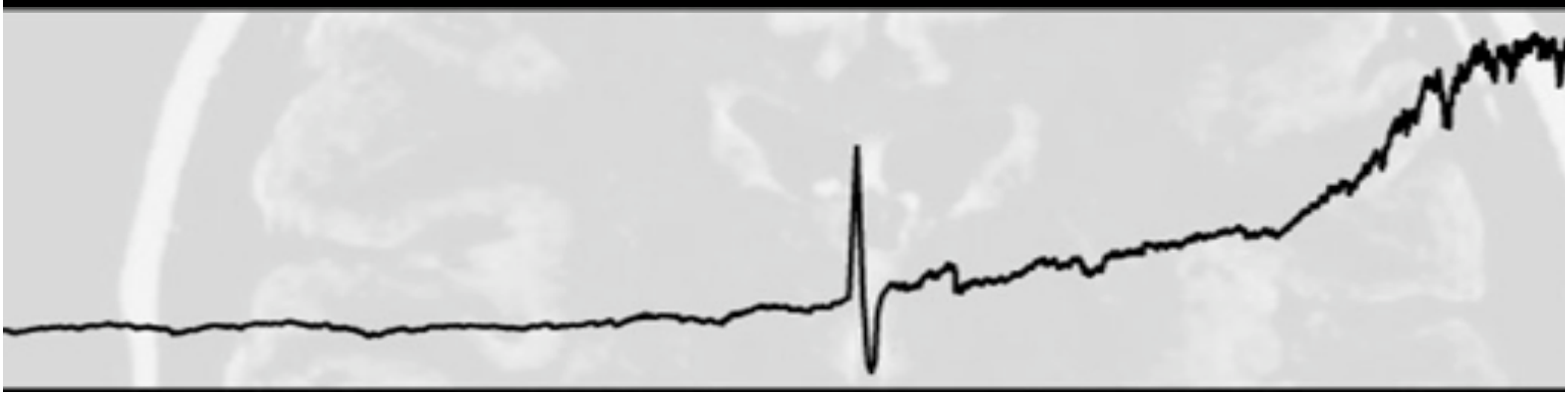
Meeting Program



Neuroeconomics: Decision Making and the Brain

8TH ANNUAL MEETING

EVANSTON, IL

OCTOBER 15-17, 2010

SOCIETY FOR NEUROECONOMICS

Schedule of Events for Neuroeconomics 2010, Evanston, IL

General sessions will be held in the Grand Ballroom Parlor AB, and all meals and breaks will be served in Grand Ballroom Parlor CD unless indicated otherwise below.

Friday, October 15, 2010

8:00 – 9:00 am	*Continental Breakfast*		
9:00 am – 12:30 pm	Workshops in the Foundations of Neuroeconomics		
	The two workshops will occur simultaneously, and you may choose which one you would like to attend.		
	Neuroscience for Social Scientists *Location: Northshore Room* This workshop is sponsored by the **Behavioral and Social Neuroscience PhD program at Caltech**		Economics for Neuroscientists *Location: Grand Parlor AB* This workshop series is sponsored by the **Zell Center for Risk Research at the Kellogg School of Management**
9:00 – 10:30 am	The neurobiology of dopamine Paul Phillips, University of Washington		Axiomatic models in economics and neuroscience Mark Dean, Brown University
10:30 – 11:00 am	*Coffee Break*		
11:00 am – 12:30 pm	The role of dopamine in learning and decision making: Multiple levels of analysis Michael Frank, Brown University		Reference-dependent preferences Botond Kőszegi, University of California, Berkeley
12:45 – 1:45 pm	*Lunch & Lunchtime speaker Clement Levallois* *Whose field is it? Disciplinary interactions in neuroeconomics*		*Grand Ballroom Parlor CD (Lunch also served in: Heritage Ballroom)*
1:50 – 2:00 pm	Antonio Rangel President, Society for Neuroeconomics	Welcome & Opening Remarks	

Session I: Discounting

Chair: Camelia Kuhnen

2:00 – 2:20 pm	Franz H. Heukamp	Should I risk or wait? Probability-time trade-off and its dopaminergic modulation	Franz H. Heukamp, Maite Aznárez-Sanada, Maria A. Fernández-Seara, Francis R. Loayza, Ewa Salamon-Klobut, and Maria A. Pastor
2:25 – 2:45 pm	Koji Jimura	Dynamically evolving representation of subjective value during human intertemporal decision making	Koji Jimura, Bruna S. Martins, Maria S. Chushak and Todd S. Braver

Session II: Risk

Chair: Michael Platt

2:50 – 3:10 pm	Giorgio Coricelli	Assessing strategic risk with fMRI	Giorgio Coricelli, Andrea Brovell, Frank Heinemann, and Rosemarie Nagel
3:15 – 3:35 pm	Hiroshi Yamada	Well-trained rhesus monkeys are risk averse for fluid rewards	Hiroshi Yamada and Paul W. Glimcher
3:45 – 5:45 pm		Poster Session I & *Cash Bar*	*Location: Heritage Ballroom & 2nd Floor Foyer*
6:00 – 8:00 pm	*All-Attendee Banquet*		
6:45 – 7:45 pm	***The Kavli Foundation Plenary Lecture*** *Wolfram Schultz* *Predictive, subjective and adaptive coding of reward value and risk*		

Special Evening Event

Join us for a bonfire at the beach!

This event is sponsored by the **Center for Neuroeconomics at New York University**

Where: Lakefill fire pit (see map handed out at registration)
When: 8:00 – 11:00 pm, Friday, October 15, 2010
What: Bonfire, s'mores, open bar*, and fresh air
**Open bar includes choice of two beers, house wines, sodas, and bottled water.*

Saturday, October 16, 2010

8:00 – 9:00 am *Continental Breakfast*

Session III: Affect & Liking

Chair: Nai-Shing Yen

9:00 – 9:20 am	Katia M. Harlé	The neural basis of mood-driven biases in social economic decision making	K.M. Harlé, L.J. Chang, M. van't Wout and A.G. Sanfey
9:25 – 9:45 am	Kaisa Hytönen	Path-dependence in risky choices: role of affect and cognitive control	K. Hytönen, A. Smidts, G. Baltussen, M.J. van den Assem, V. Klucharev, and A.G. Sanfey
9:50 – 10:10 am	Gregory Berns	A neural predictor of cultural popularity	Gregory S. Berns and Sara E. Moore

10:15 – 10:45 am *Coffee Break*

Session IV: Social Decision Making

Chair: Kevin McCabe

10:45 – 11:05 am	Corey McMillan	The neural basis for establishing a focal point in pure coordination games	C.T. McMillan, M.C. Khella, K. Rascovsky, R. Clark, and M. Grossman
11:10 – 11:30 am	Dongil Chung	Neural predictors and spatiotemporal dynamics of free-riding	Dongil Chung, Kyongsik Yun, Jaeseung Jeong
11:35 – 11:55 am	Ernst Fehr	The neuroeconomics of social norm compliance	Ernst Fehr

12:00 – 1:30 pm *Buffet Lunch*

12:30 – 1:30 pm *Federal Funding Opportunities for Neuroeconomics – A Roundtable Discussion with NIH and NSF Program Officers* *Grand Ballroom Parlor CD (Lunch also served in: Northshore Room)*

1:30 – 3:30 pm Poster Session II *Location: Heritage Ballroom & 2nd Floor Foyer*

Session V: Learning and Choice I

Chair: Eric Johnson

3:45 – 4:05 pm	Greg Samanez-Larkin	Learning and decision making in the aging brain	G.R. Samanez-Larkin and B. Knutson
4:10 – 4:30 pm	Jamie Roitman	Nucleus accumbens responses differentiate action selection following Go and NoGo cues	J.D. Roitman, A.L. Loriaux, and M.F. Roitman
4:35 – 4:55 pm	Michael Platt	Neuronal implementation of optimal foraging decisions	Michael L. Platt and Benjamin Y. Hayden

Afternoon off; dinner on your own—

6:00 – 7:30 pm *Women in Neuroeconomics Cocktail Hour*
Discussion panel led by: E. Weber, L. Nielsen, L. Phelps, H. Plassmann, C. Kuhnen, and D. Shohamy
Location: Hinman Auditorium and Foyer, 9th floor

Sunday, October 17, 2010

8:00 – 9:00 am		*Continental Breakfast*	
9:00 – 9:10 am	Antonio Rangel President, Society for Neuroeconomics	Announcements Presentation of YIA award	

Session VI: Learning and Choice II

Chair: Scott Huettel

9:10 – 9:30 am	Matthew Wanat	The stress-related peptide, corticotropin-releasing factor, acts in the ventral tegmental area to attenuate phasic dopamine release to rewards but not their predictors	Matthew J. Wanat, Antonello Bonci, and Paul E. M. Phillips
9:35 – 9:55 am	Jian Li	Differential roles of human striatum and amygdala in associative learning	Jian Li, Daniela Schiller, Geoffrey Schoenbaum, Elizabeth A. Phelps, and Nathaniel D. Daw
10:00 – 10:20 am	Elise Payzan-LeNestour	Risk, estimation uncertainty, and unexpected uncertainty: Brain mechanisms mediating Bayesian learning under three kinds of uncertainty	E Payzan-LeNestour S Dunne, P Bossaerts, and J O'Doherty
10:25 – 10:55 am		*Coffee Break*	

Session VII: Valuation I

Chair: Hilke Plassmann

11:00 – 11:20 am	Z Kurth-Nelson	Effects of contingency representation on decision making	Z. Kurth-Nelson and A.D. Redish
11:25 – 11:45 am	Klaus Wunderlich	Markowitz in the brain: learning about correlated rewards	Klaus Wunderlich, Mkael Symmonds, Peter Bossaerts, and Ray Dolan
11:50 am – 12:10 pm	Camillo Padoa-Schioppa	Dissociating economic choice from action planning: Contributions of orbital and lateral prefrontal cortices	Camillo Padoa-Schioppa
12:15 – 1:15 pm		*Buffet Lunch*	

Session VIII: Valuation II

Chair: Peter Bossaerts

1:20 – 1:40 pm	Hauke Heekeren	How the brain integrates costs and benefits during decision making	Hauke Heekeren
1:45 – 2:05 pm	Cary Frydman	The neurobiological basis of realization utility during stock-market transactions	Cary Frydman, Colin Camerer, Nick Barberis, Antonio Rangel

Please exit the Grand Ballroom Parlor by 2:30PM
Thank you for your cooperation and see you next year!

Poster Session I: Friday 3:45PM - 5:45PM		
#	Title	Authors
1	Phasic dopamine release during reward learning under uncertainty	Andrew S. Hart and Paul E. M. Phillips
2	Memory-based decision making: hippocampally-linked representations underlie behavior in a rewarded choice task	A. M. Bornstein and N.D. Daw
3	Time-course of Encoded Expected Utility Revealed by Single Neuron Activity in the Human Amygdala	Rick L. Jenison, Christopher K. Kovach and Martina Chura
4	Appetitive States Toggles a Neuronal Switch for Aproach/Avoidance	Keiko Hirayama and Rhanor Gillette
5	The Nature of Salience in Strategic Games: Predictions from Visual Neuroscience	Milica Milosavljevic, Alec Smith, Christof Koch, and Colin Camerer
6	Neural substrates of delay discounting in smokers and nonsmokers	Sarah Tappon, Vanessa B. Wilson and Suzanne H. Mitchell
7	Decision Making and the Brain: Decision Strategies In the Psychopathic Brain	D. T. Wargo and G. L. Spencer
8	The neural correlates of primary and secondary costs in economic decision-making	Hilke Plassmann, Nina Mazar, and Antonio Rangel
9	An addiction to stuff? An fMRI study to determine if common neural circuits underlie decisions about cotton balls and crack	John M. Wang, Rachael D. Seidler, Julie L. Hall, and Stephanie D. Preston
10	The Time Course of Value Computations at the Time of Decision Making	Alison Harris, Ralph Adolphs, Colin C. Camerer, and Antonio Rangel
11	The Neuroeconomics of Nicotine Dependence: Understanding Intertemporal Choice in Smokers using fMRI	Michael Amlung, James MacKillop, Lawrence Sweet, Lauren Wier, Sean David, Beth Jerskey, Lara Ray, James Murphy, Ronald Cohen, and Warren Bickel
12	When you keep changing your mind: The neural basis of preference reversals	Joseph W. Kable and Jessica Stump
13	The value computations in vmPFC and the striatum are guided by visual attention	Seung-Lark Lim, John P. O'Doherty and Antonio Rangel
14	Genes, Economics, and Happiness	Jan-Emmanuel De Neve, James H. Fowler, Bruno S. Frey, and Nicholas A. Christakis
15	OFC Value Neurons Do Not Have Spatial Tuning	Lauren Grattan and Paul W. Glimcher
16	BOLD Response During Passive Viewing of Stimuli Predicts Subsequent Economic Choice	Alec Smith, Doug Bernheim, Colin Camerer, and Antonio Rangel
17	Frontal Asymmetry and Delay Discounting	Jacob B. Hirsh
18	The Effect of Short-term Affective Modulation on Reward Prediction Error Signal: A Study of Feedback-related Negativity	Chun-Yu Chen, Nai-Shing Yen and Ruey-Ming Liao

19	Preferences During Repeated Visual Probabilistic Choice	Julia Trommershaeuser, Elke U. Weber, Eric J. Johnson, and Paul W. Glimcher
20	Monetary Reward and Intrinsic Motivation: Neural Basis of Motivation Crowding-Out Effect	K. Matsumoto, K. Murayama, M. Matsumoto, and K. Izuma
21	Discounting Time and Probability by Perception of Reward	William H. Alexander and Joshua W. Brown
22	Normalized value coding underlies irrational choice behavior	Kenway Louie and Paul Glimcher
23	Individual Variance across Probability Discounting, Reversal Learning, and Working Memory in Rats	L.K. Graham, J.K. Chan, D.C. Castro, and J.J. Kim
24	BOLD correlates of evidence integration during value-based decision making	Ryan Jessup, Antonio Rangel, and John P. O'Doherty
25	Shockingly conservative: Threat of shock increases risk aversion	Peter Sokol-Hessner, Jeffrey Hamilton, Colin Camerer, Elizabeth Phelps
26	Chronic marijuana use is associated with distinct neural activity during monetary decision-making	Jatin G. Vaidya, Robert I. Block, Daniel S. O'Leary, Laura B. Ponto, Mohamed M. Ghoneim, and Antoine Bechara
27	Effector-Specific Reward Value Updating in the Posterior Parietal Cortex	Y.T. Wong, M.M. Fabiszak, Nathaniel D. Daw, and B. Pesaran
28	A Neural Substrate of Probabilistic and Intertemporal Choice Within a Single fMRI Experiment	Hiroyasu Yoneda and Sobei H. Oda
29	Working Memory and Intertemporal Choice	Sarah J. Getz, Damon Tomlin, Leigh E. Nystrom, Jonathan D. Cohen and Andrew R. A. Conway
30	Neural Correlates of Cognitive Dissonance and Choice-Induced Preference Change	Keise Izuma, Madoka Matsumoto, Kou Murayama, Kazuyuki Samejima, Norihiro Sadato, and Kenji Matsumoto
31	Rats respond to the opponents' change in strategy in a competitive game	Tassi, LE and Xavier, GF
32	Exposure to Economic Arguments Reduces Delay Discounting	Nicole Senecal and Joseph W. Kable
33	Subliminal Brand Priming Influences Incidental Decision-Making	Philip G. Harris, Carsten Murawski, Stefan Bode, Juan F. Domínguez D., and Gary F. Egan
34	Frontopolar cortex contributes to choice exploration by tracking recent payoff trends	Christopher K. Kovach, Nathaniel Daw, David Rudrauf, Daniel Tranel, John P. O'Doherty, Ralph Adolphs

Poster Session II: Saturday 1:30PM - 3:30PM		
#	Title	Authors
1	Behavioral and Neurobiological Evidence for Probabilistic Sophistication	Mathieu d'Acremont, Eleonora Fornari, and Peter Bossaerts
2	Differentiating cooperative motives and affective reactions in prosocials and proselfs with fMRI	Griet Emonds, Carolyn H. Declerck, Christophe Boone, Ruth Soerinck, & Rik Achten
3	Neural Computations underlying Strategic Learning	Lusha Zhu, Kyle Mathewson, and Ming Hsu
4	Overlapping Neural Activation in Delay Discounting and Working Memory: A Meta-Analysis	Warren K. Bickel, Jeffery A. Pitcock
5	Comparing Apples and Oranges: Evidence for a Unified Subjective Value Representation in the Brain	D. Levy and P.W. Glimcher
6	Towards a Mathematical Psychiatry: Rational Modeling of Obsessive Compulsive Repetition (OCR) with Decision and Game Theory	L. Amsel and A. Pilpel
7	Noradrenaline in decision-making: pupil dilation reflects unexpected uncertainty	K. Preuschoff, B.M. ‘t Hart, W. Einhäuser
8	Neural Correlates of Anticipation Risk Reflect Risk Aversion	S. Rudorf, K. Preuschoff, C. E. Elger, and B. Weber
9	Prior and likelihood uncertainty are differentially represented in the human brain	Iris Vilares, James D Howard, Hugo L Fernandes, Jay Gottfried, and Konrad Kording
10	Motivational and Neural Differences in Reward and Risk Anticipation	John A. Clithero, R. McKell Carter, Vinod Venkatraman, David V. Smith, and Scott A. Huettel
11	Social Learning in Asset Markets: A Peek into the Herding Brain	Holger Gerhardt, David Danz, Guido Biele, Harald Uhlig, Dorothea Kübler, and Hauke R. Heekeren
12	Stochastic choice behavior predicted by the BOLD signal	Stephanie C. Lazzaro, Robb B. Rutledge, Daniel Burghart, Ifat Levy and Paul W. Glimcher
13	Different Affective Learning Systems Contribute to the Accumulation of Assets and Debt	Camelia M. Kuhnen, Brian Knutson, Gregory R. Samanez-Larkin
14	Genetic Modulation of DRD4 VNTR – Linear Relation between Functional Efficiency and Economic Uncertainty Preferences	O.A. Mullette-Gillman, E. McClaurin, K.M. Schiabor, R. Phillips, A. Robinson, E.T. Cirulli, D. Goldstein, M. Platt, J.H.P. Skene, and S.A. Huettel
15	Social Components of Motivated Deception	R.M. Carter, D.L. Bowling, and S.A. Huettel
16	An Expected Utility Maximizer Walks Into A Bar	Daniel R. Burghart, Stephanie Lazzaro, and Paul W. Glimcher
17	A Neural Model of Stochastic Behaviour Applied to Mixed Strategy Games	Ryan Webb
18	Functional coupling between hippocampus and prefrontal cortex is associated with willingness to wait for larger monetary rewards	Shan Luo, George W. Ainslie, Drusus Pollini, Lisa Giragosias, John R. Monterosso
19	Risky decision making and development: Neural recruitment from childhood to adulthood	David Paulsen, McKell Carter, Michael Platt, Scott Huettel, Elizabeth Brannon

20	Spontaneous lies in social contexts are associated to reduced motor readiness	Panasiti MS, Pavone EF, Mancini A, Merla A, Aglioti SM
21	Ventromedial prefrontal cortex interacts with posterior superior temporal cortex during valuation of social rewards	David V. Smith, John A. Clithero, Sarah E. Boltuck, Scott A. Huettel
22	Loss aversion in perceived ownership: An fMRI study of economic decision making	C. Buerger, J. Weghmann and B. Weber
23	Optimal Information Integration in a Hierarchical Decision Task	Ulrik Beierholm, Klaus Wunderlich, Peter Bossaerts and John P O'Doherty
24	Strategic and Social Decision-Making Mechanisms Support Language Processing	C. T. McMillan , R. Clark, D. Gunawardena, M. Dreyfuss, and M. Grossman
25	Double asymmetry of reciprocity: a behavioral and neurobiological study	A. Riedl, S. Okamoto-Barth, M. Strobel, A. Heinecke, H. Breman, and R. Goebel
26	How certain are you? Explicit and Implicit Measures of Decision Confidence	Joshua Sanders and Adam Kepecs
27	Value transfer in human sensory preconditioning with monetary reinforcement	G. Elliott Wimmer and Daphna Shohamy
28	The Neural Basis of Expectations in Social-Bargaining	Luke J. Chang, Alec Smith, and Alan G. Sanfey
29	Neural correlates of the influence of extrinsic rewards on intrinsic motivation	K. Albrecht, J. Abeler, B. Weber, and A. Falk
30	The Minimax Matching Hypothesis	Liam Clegg
31	The Neural Basis of Wage Valuation in Economic Search Under Uncertainty	J. Heinonen, J. Suomala, L. Palokangas and J. Numminen
32	The Dark Side of Product Attachment: Reactivity of Users and Non-Users to Addictive Product Advertising	Dante Pirouz, Cornelia (Connie) Pechmann, and Paul F. Rodriguez
33	Insensitivity to Rejection in the Ultimatum Game: Evidence from Frontotemporal Dementia	Katya Rascovsky, Corey T. McMillan, Peachie Moore, Robin Clark, Brianna Morgan and Murray Grossman

Friday, October 15, 2010

Workshop: Neuroscience for Social Scientists

Northshore Room

Session I: 9:00 – 10:30 am
The neurobiology of dopamine

Paul Phillips
University of Washington

The neurotransmitter dopamine has received a lot of attention in the field of neuroeconomics due to its unequivocal contribution to economic decision making. However, dopamine's role in updating the values assigned to environmental stimuli and promoting motivated behavior is complex. This lecture will explore the signaling properties of dopamine that endow it with its unique capacities in the modulation of motivated behaviors.

~Coffee Break~

Session II: 11:00 – 12:30 pm
The role of dopamine in learning and decision making: Multiple levels of analysis

Michael Frank
Brown University

This workshop will discuss the roles of dopamine in learning and decision making. It will begin with a survey of recent findings in rodents and monkeys, followed by human studies, in all cases from a range of methods. Computational models at various levels of abstraction will be discussed. It will be argued that dopamine is multi-faceted, having different functions across multiple time scales and across distinct subcortical and cortical brain areas, but that all of these local functions converge to support motivated behavior more generally.

Caltech

This workshop is sponsored by the Behavioral and Social Neuroscience PhD program
at the California Institute of Technology.

Friday, October 15, 2010

Workshop: Economics for Neuroscientists

Grand Parlor AB

Session I: 9:00 – 10:30 am
Axiomatic models in economics and neuroscience

Mark Dean
Brown University

Economists have a long history of using axioms to understand the behavioral implications of models that rely on unobservable elements. These axioms provide simple, testable implications of entire model classes, free of ad hoc assumptions about the nature of these unobservables. For example, the weak axiom of revealed preference provides a clean way of testing whether choice can be modeled as the result of utility maximization, without having to make any assumptions about what creates utility. This talk will describe the axiomatic underpinnings of classic models of economic choice - utility maximization, expected utility and subjective expected utility - and how the axiomatic approach has spurred interactions between theoretical and empirical work. It will also show how the same approach can be applied to a neuroeconomic problem - whether dopamine encodes a reward prediction error.

~Coffee Break~

Session II: 11:00 – 12:30 pm
Reference-dependent preference

Botond Kőszegi
University of California, Berkeley

This workshop is sponsored by the Zell Center for Risk Research at the Kellogg School of Management.

Friday, October 15, 2010

Lunchtime Presentation

Grand Parlor CD

Clement Levallois, PhD

Rotterdam School of Management, Erasmus Univesity

Whose field is it?
Disciplinary interactions in neuroeconomics

C. Levallois,[12*] A. Smidts[1] and P. Wouters.[2]

[1]Rotterdam School of Management, Erasmus University; [2] Erasmus Studio, Erasmus University Rotterdam

[*]Correspondence at: clevallois@rsm.nl

Neuroeconomics makes a strong claim to transcend traditional disciplinary boundaries. But "how much" interdisciplinarity can be found in neuroeconomics, and of "what kind" is it?

We first compare neuroeconomics with two other attempts to build collaborations across the natural and social scientific fields: evolutionary economics and social and affective neuroscience. The comparison focuses on journals of publication and on the authors's host institutions. It reveals that evolutionary economics and social and affective neuroscience are practiced and published in distinct subsets of the scientific spectrum but without ever "breaking in" the other side of the natural science / social science border. In contrast, neuroeconomics appears to be the product of a richer interdisciplinary mix. Specifically, its footprint in publications extends from neurosciences to economics and management journals and through psychology to top-generalist scientific journals. The host institutions of neuroeconomists reflect a similarly diverse disciplinary background. A measure of their h-index suggests that economists involved in neuroeconomics have a wide influence in their field of origin, which proves a further contrast with evolutionary economics. The results of this bibliometric analysis are discussed by putting them in a summarized historical perspective: the degree of interdisciplinarity interactions in neuroeconomics appears to be the exception, not the rule.

In a second step, we probe the nature and structure of the disciplinary mix composing neuroeconomics. We exploit the results of a worldwide survey conducted in 2009 among neuroeconomists which yielded data on the communities and social networks which altogether constitute neuroeconomics. While the data is still being processed, the main provisional result suggests a so-called centre / periphery structure. Communities with a relatively large number of social scientists are situated at the periphery of the neuroeconomics network, and clusters composed mainly of natural scientists would be at the core. Interviews with neuroeconomists suggest that this result might not reflect the self-perceptions that neuroeconomists have of how their discipline is evolving, meaning that our findings could operate as an interesting feedback to the community of neuroeconomists.

THE KAVLI FOUNDATION

Friday, October 15, 2010

The Kavli Foundation Plenary Lecture:

Grand Parlor CD, 6:45PM

Presented by

Wolfram Schultz, MD, PhD, FRS

Department of Physiology, Development & Neuroscience, University of Cambridge, UK

Predictive, subjective and adaptive coding of reward value and risk

We investigated basic neuronal reward and risk processes important for decision making using neurophysiological methods in monkeys and brain imaging in humans.

Informed decisions between different rewards are based on predictions about future outcomes. We investigated the nature of reward predictive neuronal signals in the amygdala by manipulating the informative nature of the predictive stimulus. We changed the contextual background reward while keeping stimulus reward constant. True reward predictive responses reflected the difference between background and stimulus reward, suggesting that reward contingency rather than simple stimulus-reward pairing (contiguity) determined the predictive neuronal responses.

Reward value appears to depend on the individual decision maker and the environment, and hence is subjective. Dopamine neurons in monkeys, and likely downstream striatal activations in humans, discounted reward value across temporal delays of a few seconds despite unchanged objective reward value, suggesting subjective value coding.

Reward predictions inform about probability distributions of reward values with varying degrees of risk. Subpopulations of orbitofrontal and striatal neurons, and most dopamine neurons, showed adaptation of reward related responses to the mean and variance (risk) of predicted probability distributions of reward value. These data suggest matching of distributions between neuronal output responses and reward input, resulting in effective reward coding akin to sensory adaptation. Adaptive teaching signals provide stability of learning and established performance in noisy environments. Adaptive neuronal coding may explain such behavioural phenomena as reference dependent coding.

The processing of risky outcomes depends on the subjective perception of risk and, separately, on the personal attitudes of individual decision makers towards risk. Dopamine and orbitofrontal neurons in monkeys showed distinct risk signals that were unlikely to constitute value or utility signals. In humans, risk signals and the influence of risk on value signals covaried with individual risk attitudes in subregions of prefrontal cortex, suggesting subjective coding of risk and its influence on reward value.

Taken together, these data demonstrate the nature of neuronal reward predictions and suggest subjective coding of key reward variables via temporal delays and adaptive processes in main reward structures of the brain.

Friday, October 15, 2010

Abstracts for Session I

Discounting

Chair: Camelia Kuhnen

2:00 – 2:20 pm	Franz H. Heukamp	Should I risk or wait? Probability-time trade-off and its dopaminergic modulation	Franz H. Heukamp, Maite Aznárez-Sanada, Maria A. Fernández-Seara, Francis R. Loayza, Ewa Salamon-Klobut, and Maria A. Pastor
2:25 – 2:45 pm	Koji Jimura	Dynamically evolving representation of subjective value during human intertemporal decision making	Koji Jimura, Bruna S. Martins, Maria S. Chushak and Todd S. Braver

Should I risk or wait? Probability-Time trade-off and its dopaminergic modulation.

Franz H. Heukamp[1*], Maite Aznárez-Sanado[2], Maria A. Fernández-Seara[2], Francis R. Loayza[2], Ewa Salamon-Klobut[1], and Maria A. Pastor[2]
[1]IESE Business School; [2]Functional Neuroimaging Laboratory, Center for Applied Medical Research, University of Navarra.
[*]Correspondence at: fheukamp@iese.edu

Objective: Delay and risk are attributes of virtually any economic decision. Some have considered them substitutes for each other and the trade-off between both dimensions is little explored. We tested the hypothesis that (1) delay and risk can be traded-off and (2) are fundamentally the same thing and thus mediated by the same neurological pathway. Moreover, we study how this trade-off is modulated by the dopaminergic system.

Methods: Forty-five adult subjects (twenty-six of them female) participated in the study. One group of fifteen subjects was medicated with a dopaminergic D2-antagonist, metoclopramide; another group of fifteen received a placebo. Each subject made a series of choices for real monetary gains that involved a fixed amount of €30 to be received at a time *t* that varied between 1 and 7 months and with a probability *p* between 20% and 80%.
Subjects were scanned using fMRI while making the choices. We analyzed the data with the GLM in SPM5. As a parametric regressor we included the prediction of the Probability Time Trade-off (PTT) economic model which links traditional trade-offs, outcome-time and outcome-probability in a single measurement, thereby quantifying the subjective value of a delayed and probabilistic outcome.

Results: Through regression analysis between the BOLD signal and the PTT model index identified the neural substrate encoding the subjective reward value. In addition, we located the brain regions where the BOLD activity was correlated with time delay and outcome probability, or with their interaction. Activity in the Anterior Cingulate Cortex was related to both the effect of outcome probability and time delay, while the Basal Ganglia and Cerebellum were found to play a key role in their interaction.
After the administration of metoclopramide, subjects showed a propensity to postpone the reward in order to increase the outcome probability. In these conditions, the Basal Ganglia were no longer involved in the interaction between probability and delay. The neural activity detected that was correlated with the PTT index regressor paralleled the change in the subjective value of the reward experienced in the metoclopramide treated subjects.

Conclusions: These results suggest that (1) the trade-off between delay and risk is natural for subjects and (2) the same neurological pathways mediate risk and delay when a direct trade-off between the two dimensions, albeit with distinct intensity. The trade-off between delay and risk is very sensitive to a pharmacological manipulation; this makes the experimental task a good test for the onset of changes in the human dopaminergic system.

Acknowledgements:
This work was funded by a grant from the Foundation for Applied Medical Research (FIMA) University of Navarra and EUROCORES by the European Science Foundation.

Dynamically evolving representation of subjective value during human intertemporal decision-making.

Koji Jimura, Bruna S. Martins, Maria S. Chushak, and Todd S. Braver
Department of Psychology and Radiology, Washington University in St. Louis

To whom correspondence may be addressed to KJ (koji.jimura@gmail.com).

Objective: Theoretical models of intertemporal decision-making have postulated that subjective values (SV) of a delayed outcome are dynamically represented during the delay following a decision (1, 2). However, there has been no direct evidence for this hypothesis in human reward-based decision-making (see (3) for results related to forced-choice punishments). The current study utilized a recently developed delay-discounting paradigm (4) to measure human brain activity as it continuously evolved across the complete set of decision-related events: choice, delay, and consumption.

Methods: In each trial, participants made a decision, waited for a delay (0~60 sec), and then consumed a liquid reward (2~16 ml). Importantly, choice parameters were systematically varied in relation to individuals' SVs estimated in a separate behavioral session, in order to bias choice decisions toward delayed options. This manipulation enabled us to measure delay-related activation within a decision-making context.

Results and Discussion: Behaviorally, the probability of choosing the delayed option was lower and choice reaction times were increased, as the choice options were closer in terms of estimated SV, suggesting greater decision difficulty. The decision difficulty effect was correlated with increased activation in multiple subcortical regions including nucleus accumbens (NAcc), and this effect was further amplified in individuals showing steeper delay discounting. Further, during the post-choice delay period, NAcc activation increased as the reward outcome approached, and was also sensitive to discounting individual differences, with steep discounters showing stronger delay-related activation. Model-based analyses identified ventromedial prefrontal cortex for which delay activation dynamics were explained by the hyperboloid discount function f(k,t) (k: discount factor; t: time). Conversely, a model including an "anticipation" term modeled as 1-f(k,t) (c.f. 1,3) identified bilateral orbital cortex sensitive to this variable. Together, these results confirm that neural reward circuitry is engaged not only during choice periods but also in a dynamic manner during the delay. Moreover, the findings suggest that delay discounting phenomena may reflect the nature of medial and lateral frontal encoding of future rewards during the delay, not only in terms of SV, but also in terms of the anticipatory (i.e., goal-directed) utility of waiting.

References: (1) Loewenstein Econ J 97, 666, 1987. (2) Rangel et al. Nat Rev Neurosci 9 545, 2008. (3) Berns et al. Science 312, 754, 2006. (4) Jimura et al. Psychon Bull Rev 16, 1071, 2009.

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Friday, October 15, 2010

Abstracts for Session II

Risk

Chair: Michael Platt

2:50 – 3:10 pm	Giorgio Coricelli	Assessing strategic risk with fMRI	Giorgio Coricelli, Andrea Brovell, Frank Heinemann, and Rosemarie Nagel
3:15 – 3:35 pm	Hiroshi Yamada	Well-trained rhesus monkeys are risk averse for fluid rewards	Hiroshi Yamada and Paul W. Glimcher

Assessing strategic risk with fMRI

Authors: Giorgio Coricelli (CNRS Lyon), Andrea Brovelli (CNRS Marseille), Frank Heinemann (TU-Berlin), and Rosemarie Nagel (UPF-ICREA)

We used fMRI to measure the neural correlates of strategic uncertainty in games and lotteries. Participants played a series of stag hunt games, entry games, and lotteries. The two games differ in their equilibrium properties: stag hunt games are games of strategic complementarity (e.g., an investment pays off if and only if a sufficient number of agents invest in the same industry, so all invest and nobody invest are two Nash equilibria) while entry games are of strategic substitutability (e.g., if too many agents invest in a new market all get nothing; here we should not all do the same, but instead choose mixing strategies in equilibrium). A mentalizing network (mPFC, TPJ, STS, precuneus) is activated in games playing vs. Lotteries, thus distinguishing the social and the private nature of the choice context. Furthermore, we found a behavioral correlation and a similar pattern of activity in the striatum between choosing lotteries and choosing the stag hunt game; while insula and lateral OFC activity was mainly related to entry games choices. Interestingly, we found a clear separation of insula activity in lotteries and stag hunt games when distinguishing between risk averse and risk loving players. However, in entry games this distinction is not at all found. We conclude that the entry game creates more strategic uncertainty as predicted by the nature of the theoretical equilibrium which also involves levels of reasoning. While the strategic uncertainty of the stag hunt game can be "reduced" to standard risk, the uncertainty underlying entry games is higher and analogous to ambiguous choices.

Well-Trained Rhesus monkeys are risk averse for fluid rewards

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Human and animal choosers should be, under most conditions, risk-averse in their choices and literally hundreds of studies in humans and several other species have validated this normative prediction under technically demanding conditions. Technically, risk aversion (or risk seeking) is defined as negative (or positive) curvature of the utility function observed under conditions in which choice behavior is complete, transitive, and (for some definitions) obeys the Independence Axiom of Expected Utility Theory. A recent study of rhesus monkeys has, however, suggested that these subjects may be risk-seeking for fluid rewards (McCoy et al, 05). That conclusion, however, was drawn under conditions in which choice behavior may not have been transitive or sensitive to the Independence Axiom – a condition under which the label 'risk-seeking' would not be technically apply.

To measure the risk attitudes of rhesus monkeys as a function of training, we taught two monkeys to engage in a visual gambling task based on human studies of risk attitudes. In this task the animals chose between a risky and a certain option that varied systematically in value. While fixating a central point, the monkeys received visual cues indicating the payoff volume of fluid reward offered by two options located on the left and right sides which varied from trial-to-trial. Option values ranged from 0 ml to 0.60ml in 0.06ml increments. The probability that the risky option would yield a reward was fixed at 50% across lotteries. After monkeys showed stable choice a total 7115 and 3843 choices were recorded in each of the two monkeys during 17 days of data collection. We assessed risk attitudes by fitting a power utility function and a logit noise term to the choices of the animals under an assumption in which the winning probability is objective: Utility = probability × (water amount)$^{\alpha}$. Estimated under these conditions both monkeys showed significant negative utility function curvature (alpha = 0.929 ± 0.001 and 0.928 ± 0.001). In other words, these monkeys were unambiguously risk averse for fluid rewards under these conditions.

Early in training, however, these animals were risk-seeking, perhaps in part because they appeared to employ a win-stay lose-shift like strategy, but stay more after a lose trial following consecutive winning trials. These observations suggest that monkeys, early in training, may overestimate the 50% probability of winning the risky reward, while later in training animals shifted to risk-aversion as they became familiar with a task that incentivized maximization behavior. Thus, we concluded that well-trained rhesus monkeys are risk averse for fluid rewards.

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Poster Session I: Friday 3:45PM - 5:45PM		
#	Title	Authors
1	Phasic dopamine release during reward learning under uncertainty	Andrew S. Hart and Paul E. M. Phillips
2	Memory-based decision making: hippocampally-linked representations underlie behavior in a rewarded choice task	A. M. Bornstein and N.D. Daw
3	Time-course of Encoded Expected Utility Revealed by Single Neuron Activity in the Human Amygdala	Rick L. Jenison, Christopher K. Kovach and Martina Chura
4	Appetitive States Toggles a Neuronal Switch for Aproach/Avoidance	Keiko Hirayama and Rhanor Gillette
5	The Nature of Salience in Strategic Games: Predictions from Visual Neuroscience	Milica Milosavljevic, Alec Smith, Christof Koch, and Colin Camerer
6	Neural substrates of delay discounting in smokers and nonsmokers	Sarah Tappon, Vanessa B. Wilson and Suzanne H. Mitchell
7	Decision Making and the Brain: Decision Strategies In the Psychopathic Brain	D. T. Wargo and G. L. Spencer
8	The neural correlates of primary and secondary costs in economic decision-making	Hilke Plassmann, Nina Mazar, and Antonio Rangel
9	An addiction to stuff? An fMRI study to determine if common neural circuits underlie decisions about cotton balls and crack	John M. Wang, Rachael D. Seidler, Julie L. Hall, and Stephanie D. Preston
10	The Time Course of Value Computations at the Time of Decision Making	Alison Harris, Ralph Adolphs, Colin C. Camerer, and Antonio Rangel
11	The Neuroeconomics of Nicotine Dependence: Understanding Intertemporal Choice in Smokers using fMRI	Michael Amlung, James MacKillop, Lawrence Sweet, Lauren Wier, Sean David, Beth Jerskey, Lara Ray, James Murphy, Ronald Cohen, and Warren Bickel
12	When you keep changing your mind: The neural basis of preference reversals	Joseph W. Kable and Jessica Stump
13	The value computations in vmPFC and the striatum are guided by visual attention	Seung-Lark Lim, John P. O'Doherty and Antonio Rangel
14	Genes, Economics, and Happiness	Jan-Emmanuel De Neve, James H. Fowler, Bruno S. Frey, and Nicholas A. Christakis
15	OFC Value Neurons Do Not Have Spatial Tuning	Lauren Grattan and Paul W. Glimcher
16	BOLD Response During Passive Viewing of Stimuli Predicts Subsequent Economic Choice	Alec Smith, Doug Bernheim, Colin Camerer, and Antonio Rangel
17	Frontal Asymmetry and Delay Discounting	Jacob B. Hirsh
18	The Effect of Short-term Affective Modulation on Reward Prediction Error Signal: A Study of Feedback-related Negativity	Chun-Yu Chen, Nai-Shing Yen and Ruey-Ming Liao

19	Preferences During Repeated Visual Probabilistic Choice	Julia Trommershaeuser, Elke U. Weber, Eric J. Johnson, and Paul W. Glimcher
20	Monetary Reward and Intrinsic Motivation: Neural Basis of Motivation Crowding-Out Effect	K. Matsumoto, K. Murayama, M. Matsumoto, and K. Izuma
21	Discounting Time and Probability by Perception of Reward	William H. Alexander and Joshua W. Brown
22	Normalized value coding underlies irrational choice behavior	Kenway Louie and Paul Glimcher
23	Individual Variance across Probability Discounting, Reversal Learning, and Working Memory in Rats	L.K. Graham, J.K. Chan, D.C. Castro, and J.J. Kim
24	BOLD correlates of evidence integration during value-based decision making	Ryan Jessup, Antonio Rangel, and John P. O'Doherty
25	Shockingly conservative: Threat of shock increases risk aversion	Peter Sokol-Hessner, Jeffrey Hamilton, Colin Camerer, Elizabeth Phelps
26	Chronic marijuana use is associated with distinct neural activity during monetary decision-making	Jatin G. Vaidya, Robert I. Block, Daniel S. O'Leary, Laura B. Ponto, Mohamed M. Ghoneim, and Antoine Bechara
27	Effector-Specific Reward Value Updating in the Posterior Parietal Cortex	Y.T. Wong, M.M. Fabiszak, Nathaniel D. Daw, and B. Pesaran
28	A Neural Substrate of Probabilistic and Intertemporal Choice Within a Single fMRI Experiment	Hiroyasu Yoneda and Sobei H. Oda
29	Working Memory and Intertemporal Choice	Sarah J. Getz, Damon Tomlin, Leigh E. Nystrom, Jonathan D. Cohen and Andrew R. A. Conway
30	Neural Correlates of Cognitive Dissonance and Choice-Induced Preference Change	Keise Izuma, Madoka Matsumoto, Kou Murayama, Kazuyuki Samejima, Norihiro Sadato, and Kenji Matsumoto
31	Rats respond to the opponents' change in strategy in a competitive game	Tassi, LE and Xavier, GF
32	Exposure to Economic Arguments Reduces Delay Discounting	Nicole Senecal and Joseph W. Kable
33	Subliminal Brand Priming Influences Incidental Decision-Making	Philip G. Harris, Carsten Murawski, Stefan Bode, Juan F. Domínguez D., and Gary F. Egan
34	Frontopolar cortex contributes to choice exploration by tracking recent payoff trends	Christopher K. Kovach, Nathaniel Daw, David Rudrauf, Daniel Tranel, John P. O'Doherty, Ralph Adolphs

Phasic dopamine release during reward learning under uncertainty.

Andrew S. Hart and Paul E. M. Phillips

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Humans and animals are constantly faced with decisions between prospects whose outcomes are risky or probabilistic. It is often the case that the probability and magnitude of potential outcomes are not known a priori but must be learned through repeated interactions with the environment. In well-trained primates, it has been shown that midbrain dopamine neurons fire bursts of action potentials in response to visual conditioned stimuli (CSs) that are followed by juice rewards with some probability. The magnitude of these CS-evoked increases in firing rate scale monotonically with reward probability, as well as reward value, suggesting that they represent expected value (EV) of the reward. In addition, these neurons show sustained firing between CS presentation and reward, which scales with reward variance or uncertainty of outcome. This profile of midbrain neuronal activity is consistent with the hypothesis that dopamine encodes reward prediction error (RPE) signals, which can be used to update a representation of the value associated with the CS. While these responses are well characterized in well-trained animals, little is known about the time course of their acquisition and their relationship to the acquisition of behavioral responses to the CS.

Using fast-scan cyclic voltammetry (FSCV) in rats chronically implanted with carbon fiber electrodes in the Nucleus Accumbens, we recorded dopamine release over the time course of a classical conditioning paradigm in which a light/lever CS is followed by a food pellet reward with some probability (0.25, 0.5, 0.75, or 1). We found that rats trained on this probabilistic reinforcement paradigm developed dopamine responses to the CS over a similar time course, across probabilities, and that the CS responses scaled with probability. The rats also showed dopamine responses to the reward that scaled inversely with probability, suggesting that they represent RPE signals. Sustained dopamine responses between CS onset and reward presentation were also present, but their acquisition was retarded relative to that of CS signals. These results suggest that during classical conditioning a representation the EV develops before a representation of the uncertainty associated with a CS.

Memory-based decision making: hippocampally-linked representations underlie behavior in a rewarded choice task

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Objective: Two distinct neural representations of probabilistic associations are formed during an unrewarded sequential learning task. How are these used when subjects are asked to make rewarded decisions?

Methods: We examined how reaction times (RTs) and - in a second experiment - decisions for money were influenced by associative learning about nonrewarded stimulus-stimulus or response-response contingencies in a sequential image identification task. Over the length of the task, RTs correlated with (uninstructed) image-image transition probabilities. Computational models were fit to the course of learning. Having identified correlates of learning in the absence of reward, we examined how these associations could be combined with rewards to guide decisions. In a second behavioral experiment, we sporadically interrupted the picture sequence with probe choice trials under novel reward contingencies, allowing subjects to draw on their picture sequence learning to obtain reward. Because rewards were specific to the probe, the task precluded decision by standard model-free reinforcement learning (RL) approaches.

Results: RTs were significantly better described by a mixture of two error-driven learning processes with drastically different learning rates. Using fMRI, we identified distinct correlates of each process in hippocampus and ventral striatum. For the reward trials, we leveraged our RT results as signatures each system and identified the model that best explained choices separately from RTs. A single process learning at the predetermined slow rate (the one consistent with hippocampal BOLD) described choices more accurately than the fast (striatal) rate, a freely varying rate fit solely to choices, or any combination of these.

Conclusions: These results suggest that hippocampally-dependent stimulus-stimulus representations are used in reward-based decision making in a task that encourages forward planning of a type not supported by model-free RL. They also demonstrate a novel link between reward-based decision making and hippocampal processes. Finally, they support the notion that model-free RL is insufficient for describing all human choice behavior, and provide a platform for further development of choice models describing more complex decisions requiring memory-guided planning.

Acknowledgements: This study was funded by a McKnight Scholar Award and a NARSAD Young Investigator Award.

Time-course of Encoded Expected Utility Revealed by Single Neuron Activity in the Human Amygdala

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Objective: The time-course of an encoded decision variable leading up to the point of choice cannot be directly observed but can be inferred from neural activity preceding the choice. Naive examination of the correlation between choice and integrated neural responses necessarily assumes a fixed and constant ("boxcar function") form for the decision variable over the window of integration, and thus relies on an implausible model of the temporal evolution of the signal. In order to reconstruct the time course of value encoding, we replaced the boxcar function with an orthogonal series of polynomials within a conditionally independent binomial-GLM. This approach yields a new semiparametric technique for estimating the evolution of an encoded decision variable based on single neuron activity. We apply the method to human intracranial recordings to show the dynamic evolution of uncertainty-related value signals encoded by single neurons in the amygdala.

Methods: We investigated the neural basis of uncertainty coding by recording single neuron activity in the human amygdala while patient-participants chose between the opportunity to gamble or accept a sure win. These studies were carried out in patients undergoing diagnosis and, later, surgical treatment for medically intractable epilepsy. Participants were awake and alert during recording sessions. We recorded from microcontacts implanted directly in the amygdala nuclei. We modeled the neural spiking activity using a generalized linear model (Binomial-GLM) along with a nonlinear stochastic choice model based on revealed choices. The time-course of the hypothesized decision variable was identified by introducing a set of orthogonal Laguerre basis functions as covariates into the GLM that expand the point of choice backward in time. The basis order and the Laguerre pole, which determines the rate of exponential decay, were set to support coverage of the longest single trial duration. The technology was validated using simulated Poisson process spike trains generated from a known time-varying expected utility.

Results: A nonmonotomic time-course was commonly observed with a modal region between 500 msec and 1000 msec prior to the revealed choice. The GLM fit of the Laguerre-expanded decision variable improved significantly over that of the boxcar encoding in nearly all cases using the likelihood ratio test.

Conclusions: The described polynomial expansion of neurally encoded decision variables in the GLM modeling of spike rate provides two advancements: (1) it gives a principled alternative to the assumption of boxcar-like encoding of decision variables, and (2) it reveals the time-evolution of encoding.

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Appetitive State Toggles a Neuronal Switch for Approach/Avoidance

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Goal-directed neuronal networks may express appetitive state through integrating sensation, internal state and memory, and toggle decision by corollary outputs to competing and effector networks. These relationships are accessible at the level of the networks and their identified neurons for the foraging decisions of the predatory sea-slug *Pleurobranchaea californica*.

Appetitive state is conserved in the isolated CNS, where the frequency of slow spontaneous rhythmic activity in the feeding motor network is a logarithmic relation of donor feeding thresholds. Donor CNS with high feeding thresholds (low readiness to feed) express fictive avoidance turns in response to sensory nerve stimulation; whereas hungry animals (low feeding thresholds) express orienting turns. Enhancing feeding network excitation by depolarizing feeding command neurons also reversibly changes avoidance to orienting. Serotonin added at 5 μM switches avoidance turns to orienting. Serotonin is an intrinsic modulator of both feeding network excitation and appetitive state, and its neuronal content varies with satiation state.

We find that corollary outputs from the feeding network target identified neuron connections of the turn motor network, biasing the symmetry of the turn network from avoidance to orienting in response to sensory input.

Thus, appetitive state is manifest in the excitation state of the feeding motor network, which sets sensory feeding thresholds and biases the turning motor network between approach and avoidance. The simple neuronal mechanisms of appetitive state and approach/avoidance decision in this model system may well be part of the core of more complex economic decision-making, and provide a basis for autonomous cost-benefit decision in artificial-life modeling and robotics.

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The Nature of Salience in Strategic Games: Predictions from Visual Neuroscience

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Objective: In a coordination game players choose objects from a set and prefer to choose objects that other players choose. Since Schelling (1960), the explanation for apparently high levels of coordination has been that some strategies (object choices) are more "salient" than others: they are "psychologically prominent" or "focal". Many experimental studies have explored strategy choices with indirect reference to salience, without proposing precise metrics that predict what is salient (and what is likely to be chosen) purely from stimulus properties. We introduce the idea that salience in games of choice among visually-presented objects is driven by the concept of visual salience that is well understood in psychology and neuroscience. Visual salience refers to early, automatic attention directed towards objects in a scene that "pop out" based on low-level visual features such as brightness, color, orientation, etc. We propose that, in some coordination games, players' strategic behavior is influenced by low-level visual salience.

Methods: Computational neuroscience offers a neurally-plausible algorithm of visual salience which creates a "saliency map" predicting the bottom-up time course of visual attention (Itti & Koch, 2001; Walther & Koch, 2006). We use this salience algorithm to design coordination games and predict their outcomes *ex ante*. Each game consisted of a number of strategies (6-35) represented by a variety of object labels across games (e.g., lines, circles, letters, etc.). Subjects were rewarded for choosing the same strategy as an anonymous co-player. We hypothesized that subjects' choices will be biased towards strategies with salient labels.

Results: Data from N=64 subjects show that in 7 newly designed coordination games subjects most frequently chose the label that was *ex ante* deemed to be salient by the salience algorithm. We also created 3 games in which the most salient object from one game became more or less salient in other games by manipulating its distance and orientation with regard to its neighbors. As predicted, the percentage of subjects who chose the target object decreased as the object became less salient, and increased as it became more salient. Two control games were created that do not follow the psychologically defined rules of visual saliency. In both games, the saliency algorithm failed to predict the outcome of the game.

Conclusions: A common neuromorphic saliency algorithm, based on simple visual features such as orientation, color and intensity, predicts high-level strategic choices with far above chance probability. This provides insights into the biological underpinnings of social behavior**.** An interesting question is what aspects of more complex social games (e.g. hide-and-seek games;) can also be explained using simple neurobiological plausible operations common to all subjects.

Neural substrates of delay discounting in smokers and nonsmokers

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Objectives: Smokers prefer smaller but immediate rewards over larger, delayed rewards more than nonsmokers, that is, they discount the value delayed rewards more steeply than nonsmokers (e.g., Mitchell, 1999, Psychopharm. 146, 455-464). Also, smokers prefer smaller, slightly delayed rewards over larger, more delayed rewards more than nonsmokers. However, this group difference is reduced when both rewards are delayed. We used fMRI to explore whether the neural substrates of these types of decisions differed for smokers and nonsmokers.

Methods: In an event-related design, regular smokers and nonsmokers chose between a small, immediate amount of money and a larger, more delayed reward (single-delay trials), or between a small, delayed reward and a larger, but more delayed rewards (double-delay trials). Half of the choices were designed to be difficult (alternatives were near each subject's point of subjective equality, based on the subject's past performance) and half were designed to be easy. Contrasts were used to identify differences between smokers and nonsmokers under the different decision making conditions (single- versus double-delay trials) at each level of difficulty.

Results: Both smokers and nonsmokers showed a robust response in numerous brain regions previously shown to be engaged by discounting tasks. Single-delay trials produced greater activation than double-delay trials across large swaths of the frontal and parietal cortexes, including anterior cingulate, ventromedial prefrontal cortex, and ventral striatum for smokers and nonsmokers. Hard choices were associated with more activity than easy choices in reward-related regions in the midbrain and ventral striatum and frontal regions including dorsolateral prefrontal cortex. Smokers showed more activity than non-smokers in bilateral insula and right dorsolateral prefrontal cortex, demonstrating that group differences in information processing exist even after controlling for subjective choice difficulty.

Conclusions: Results suggest similar levels of performance in smokers and nonsmokers were associated with dissimilar patterns of activation, possibly indicating that chronic exposure to nicotine is associated with reduced efficiency of neural processing.

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Decision Making and the Brain: Decision Strategies In the Psychopathic Brain

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Objective: While there has been significant research on psychopaths in institutionalized settings, there is a paucity of studies of non-institutionalized psychopaths, who make up 1% of the general population and 3.5% of business employees. Furthermore, study of the behavior and decision-making strategies of non-institutionalized psychopaths in organizations is virtually non-existent, due to privacy, logistical and bureaucratic roadblocks. We use well-validated psychopathy scales to identify individuals with psychopathic attributes and more importantly observe their decision-making and behavior in real world, long-term, small group (N=10) interactions that require cooperation to achieve real-world payoffs (= grades).

Methods: The participants in the study are 182 students (all freshmen, M= 103, F= 79) in 2 sections of an undergrad Human Resources Management class at the business school of a major research university. The psychopathic questionnaire (titled 'Success Strategy Assessment') was administered through a web-based format on Blackboard. The authors are specialized in neuroeconomics, behavioral economics, organizational dynamics and conflict management. We analyzed the 'free riding' and team disruption caused by these same individuals in team activities that required cooperation in significant, graded, semester-long projects. Six extensive peer evaluation questionnaires assessing team cohesion, individual contribution and conflict were administered, along with extensive observation by one of the co-authors.

Results: The results are fascinating and contrary to expectations. A surprising number of individuals (both male and female) endorsed psychopathic attributes that were in the second standard deviation above the mean. Further, when we correlated the total psychopathic attributes endorsed in each group with the final course grade, we found that the psychopathic attributes were additive. That is, the higher the total psychopathic score in the group, the lower was the group's course grade!

Amazingly, the strategies used by the psychopaths in the groups were quite varied. Some were simply free riders. Some hijacked the entire group and compromised the peer reports. Others attempted to manipulate the professor.

Conclusions: The influence of individuals with psychopathic attributes is magnified by group dynamics. This has been demonstrated in research showing that a large portion of the general population are 'reciprocators' who behave ethically in an ethical culture but much less so when they observe other individuals "getting away with it".

The neural correlates of primary and secondary costs in economic decision-making

Hilke Plassmann[1,2*], Nina Mazar[3], and Antonio Rangel[4]

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Background: A seminal account proposed for the hedonics underlying consumption decisions distinguishes between two opposing hedonic factors: rewarding factors like the pleasure derived from consumption and aversive factors like the costs of the consumption often referred to as "pain of paying" (Prelec & Loewenstein 1998). Previous research in neuroeconomics has investigated how the positive hedonics in form of goal values at time of choice are represented in the brain (Plassmann et al. 2007) and whether these representations differ for different modalities such as primary or secondary rewards (Chib et al. 2009). However, despite its importance for economic decision-making, little is known about how the human brain computes costs during decision-making. In particular, it is unknown if different types of costs (e.g., monetary costs vs. physical pain costs) are processed by the same brain networks. This is the central question of this paper. In particular, we investigated whether that representation differs between abstract (secondary) costs (e.g. paying money) or somatosensory (primary) costs (e.g. tolerating electric shocks) that are matched in economic value.

Background: In this paper we investigated the neural basis of cost computations by scanning hungry subjects' brains (N=21, aged 18-35, mean 23.65 years) while making 280 purchasing decisions. The fMRI task consisted of two different trial types: Trials in which subjects could decide to buy 40 food items at four different monetary prices ($0, $0.50, $1.00, $1.50) (= 160 '$ trials') and trials in which they could decide to buy the same 40 food items for tolerating pain (electric shock) at three different pain intensities (=120 'V trials') that were matched with the three different non-zero monetary prices.

Results: For the behavioral data analysis, we created dummy variables for WTP and purchasing prices in money and physical pain trials and entered them into a mixed effects logistic regression analysis. We tested differences in the regression coefficients between money and physical trials for WTP and price predictors and found significant differences (both $p<.001$). For the fMRI data analysis we estimated a hierarchical mixed effect GLM to investigate differences and overlaps for brain areas that correlated with the size of monetary and physical pain costs. We found that the bilateral insula and the thalamus, regions involved in pain processing, correlated positively with the size of physical pain prices, but not with the size of monetary prices ($p<.001$, uncorr.). A conjunction analysis revealed that no overlapping areas can be found ($p<.001$, uncorr.).

Conclusion: Taken together, these results show that people react differently to "monetary" and "pain costs" on a brain, but not a behavioral. Our fMRI results suggest that paying with money might trigger very different emotional processes than those involved with more "physical" forms of costs. These results call into question "pain of paying" theories recently suggested in the neuroeconomic literature at least for everyday consumption decisions. Our results have important implications for disadvantageous decision-making such as overspending and shopping addiction.

An addiction to stuff? An fMRI study to determine if common neural circuits underlie decisions about cotton balls and crack

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Objective: People's decisions about goods extend well beyond new purchases. Every pencil, book, t-shirt, or gadget acquired entails a chain of decisions regarding where to put it, for how long, and what to do with it when it is no longer valued. Despite a mainstream interest hoarding, little is known about the neural bases of acquiring and discarding common household goods. One could assume that such decisions are subserved by the mesolimbocortical system; however, most decision-making studies only investigate the acquisition phase and entail a monetary exchange. In contrast, we know that price is not germane to the selection and retention of common goods and work on compulsive hoarding has not found a role for the nucleus accumbens (NAcc). To directly study this issue, we contrasted decisions to acquire versus discard common goods, while maximizing personal preference vs. monetary profit.

Methods: Twenty participants (11 males) completed a block-design fMRI study using a forced-choice procedure under four nested frames. We contrasted acquisition to discarding and personal to monetary decisions (using response time as a nuisance covariate), and regressed BOLD signal responses in the regions of interest with trait measures of hoarding.

Results: The orbital frontal cortex (OFC) was involved across frames, but all other regions were significantly affected by the frame, which also changed qualitative object preferences. Monetary decisions recruited executive regions, and biased choice towards valuable (but less desired) items. Personal decisions recruited midline, affective regions and caused subjects to emphasize inexpensive, immediate rewards (candy, coins). Acquisition augmented OFC activity and biased subjects towards shiny, metal objects while discarding recruited the anterior cingulate and insula, and biased subjects towards utilitarian, "should" items. In contrast to neuroeconomic studies, acquiring such goods did not engage the NAcc, which instead was only activated during personal acquisition with the degree of trait hoarding tendencies.

Conclusions: Decisions about everyday goods may necessarily involve the OFC, but otherwise represent a complex interplay between the frame, the item, and the decider. Perhaps for acquisitive individuals even mundane goods acquire the incentive salience of more hedonic items (money, food, luxury items). Research on material goods is critical to understand a ubiquitous human decision that is critical to our economy, our quality of life, and the environment.

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The Time Course of Value Computations at the Time of Decision-Making

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Objective: In the decision-making literature, it is commonly held that the brain makes simple choices by assigning values to the stimuli under consideration, and then comparing them to select the best one. Growing evidence from electrophysiology and neuroimaging has implicated specific brain regions in value signal computations, most notably ventromedial prefrontal cortex (vmPFC) and anterior cingulate cortex (ACC). Yet the inputs to this computation, as well as its time course of activation, are unknown.

Methods: We examined the time course of value signal computations by measuring event-related potentials (ERP) while hungry subjects performed a simple choice task involving a variety of appetitive and aversive foods.

Results: Linear ERP responses consistent with value coding were observed as early as 150-250 ms after stimulus onset, with a highly significant linear response between 400 and 550 ms at central and frontotemporal sensors. We also found later frontal activity from 700-800 ms, coinciding with the average median response time (710 ms). This late response varied with differences in reaction time, showing no significant linear effect when reaction times were fast. Finally, a distributed source reconstruction localized early activity to areas of medial temporal lobe, insula, and superior frontal gyrus, with vmPFC sources observed beginning in the 400-550 ms range. Over the time window from 400 ms until response, localized source activity appeared to spread from posterior to anterior vmPFC, and from vmPFC to ACC, with more pronounced effects for trials with longer RT. Similarly, a response-locked analysis showed significant localization to vmPFC sources from approximately –240 to –160 ms, and ACC sources from about –160 to –80 ms, before response onset.

Conclusions: Our results suggest that vmPFC contributions to value signal processing reflect integration of value-related information from the medial temporal lobe, and occur relatively late in the decision process. These data provide preliminary evidence regarding the time course of value signal computations in the human brain.

The Neuroeconomics of Nicotine Dependence: Understanding Intertemporal Choice in Smokers using fMRI

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Objective: Behavioral studies have consistently found significantly more impulsive intertemporal preferences in nicotine dependent individuals compared to healthy controls. These studies use delay discounting paradigms, assessing how much a reward loses value based on its delay in time. Studies also reveal a "commodity effect", reflecting greater impulsivity for choices involving cigarette rewards. Several recent studies have examined the neuroanatomical basis for delay discounting in healthy adults using fMRI, but none have examined smokers or commodity effects, which are the foci of the current study.

Methods: The study used a within-subjects design and enrolled 15 right-handed nicotine dependent adults with no history of brain injury or MRI contraindications. Participants underwent a rapid event-related design during which they responded to 108 choices for smaller and larger commodities (half money and half the equivalent number of cigarettes) available immediately or after a delay period. Stimuli comprised 72 experimental items (smaller immediate vs. larger delayed option) and 36 control items (smaller immediate vs larger immediate). The study used a Siemens 3T TIM Trio MRI. Scanning parameters were axial orientation, TR 2500 ms, TE 28 ms, FOV = 192^2 mm, matrix = 64^2, slice thickness = 3 mm.

Results: Responses to the experimental items were classified as "impulsive" (preference for smaller immediate reward) or "restrained" (preference for larger delayed reward). Primary analyses used a disjunction mask to identify regions associated with significant activity in any of the three categories of choices (impulsive, restrained, control), identifying 23 empirical regions of interest (ROIs). These were then examined across categories to identify regions that discriminated across choice type, revealing 13 significant or trend-level effects. To reduce Type I error, a modified Bonferroni correction was applied (Hochberg step down procedure), leaving five ROIs, including the middle and medial frontal gyri, cerebellum, and precuneus. Commodity effect analyses used voxelwise paired t-tests irrespective of choice category for maximum power, revealing significant differences in the medial, middle, and inferior frontal gyri, cerebellum, and the inferior parietal lobule.

Conclusions: The results are consistent with prior studies of healthy adults, suggesting common neuroanatomical processing across samples. Commodity effects were evident and suggest biases toward tobacco cues in prefrontal regions associated with decision-making nad cognitive control. Future comparative studies and further examination of commodity effects are warranted.

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When you keep changing your mind: The neural basis of preference reversals

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Objective: Systematic inconsistencies in people's decisions provide a central challenge to rational choice theories. A classic example is the "preference reversal phenomenon" (Grether & Plott, 1979; Tversky, Slovic & Kahneman, 1990), when people choose one gamble over another, but then bid a higher price for the non-chosen gamble. Some explanations of preference reversals emphasize task-dependent changes in valuation—e.g., that the weight given to payoff versus probability information changes between choice and bidding. Other explanations focus on differences in the decision process between tasks—e.g., that people overbid on certain gambles because of an anchoring heuristic. We gathered neuroimaging data to inform the debate about the cause of preference reversals.

Methods: Preference reversals were elicited using a risky gamble paradigm in 24 subjects undergoing fMRI. In alternating scans, subjects made choices between gamble pairs or bid on single gambles. Both tasks were administered in an incentive compatible manner. Each choice involved two gambles of equal expected value, shown sequentially: one had a high probability of winning a small amount of money (termed the *P-bet*, e.g., 84% chance of $20), and another had a low probability of winning a greater amount (termed the *$-bet*, e.g., 24% chance of $70). The same gambles were used in the bidding task.

Results: Consistent with previous results in this paradigm, and with general findings of risk aversion, subjects chose the P-bet 65% of the time. However, when bidding on the gambles separately, subjects assigned a higher dollar value to the $-bet 67% of the time. Preliminary analyses identified widespread regions that showed greater activity for the preferred gamble category in each task (P-bets in choices, $-bets in bids). In medial and ventromedial prefrontal cortex and superior frontal sulcus, this effect was greater for those gamble pairs where subjects made a reversal compared to those pairs where they remained consistent across tasks. The size of this effect was also correlated across subjects with the number of preference reversals made. Furthermore, these effects were primarily driven by modulations in activity specific to the bidding task.

Conclusions: These results demonstrate that preference reversals are accompanied by changes in neural activity in medial prefrontal regions previously shown to encode subjective value (Kable & Glimcher, 2009), consistent with an explanation based on task-dependent changes in valuation. The specificity of the neural effects to bids further suggests that these changes could arise because of a cognitive process differentially engaged during bidding.

The value computations in vmPFC and the striatum are guided by visual attention

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When facing a choice between two or more stimuli, individuals typically evaluate the options by sequentially deploying their gaze to the different options, often by going back and forth. This behavioral observation suggests that visual attention might play a critical role in the value computations that are carried out in areas such as ventromedial prefrontal cortex (vmPFC) at the time of choice.

We present the results of a study design to test the hypothesis that visual attention selectively modulates stimulus value signals in ventromedial prefrontal cortex (vmPFC) and ventral striatum (vStr) at the time of decision-making. During 3-day fMRI sessions, participants (N=20) performed a real binary choice task. Every trial they were presented with pictures of two food items and were asked to alternate the focus of visual attention (eye-fixation) between the two items. The duration of each eye-fixation randomly varied from 1 to 4 sec. The vmPFC and vStr ROIs were identified by using a parametric regressor of stimulus values acquired during a separate liking-rating task.

We found that the value computations in the vmPFC and vStr were strongly modulated by the visual attention manipulation: activity correlated with the parametric regressor (V^L-V^R) when participants fixated the left item, while those ROIs were negatively correlated with this same regressor when they looked to the right item. Furthermore, a PPI analysis showed that the vmPFC exhibited significant functional connectivity with the Left STG/MTG during the left-fixation condition, and with R STG/MTG during the right-fixation condition.

Our results suggest that visual attention plays a critical role in the value computations in the vmPFC and vStr at the time of choice: the value signals in these areas seem to encode a "value of attended minus value of unattended" signal that could be useful in guiding choice.

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Genes, Economics, and Happiness

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Objective: To show the importance of genetic variation in individual subjective well-being and test a specific genetic polymorphism in the serotonin transporter gene for its neurological influence on happiness.

Methods: Using data from the National Longitudinal Study of Adolescent Health (Add Health), we first employ **twin design** methods that compare the behavior of 490 same-sex twin pairs (271MZ, 219DZ) to gauge the part of the variance in happiness (as measured by life satisfaction) that can be attributed to additive genetics (A), common environment (C), and unique experience (E). Next, a **candidate gene association** study (N=2,574) tests a functional polymorphism in the promotor region of the serotonin transporter gene (5-HTTLPR) given prior association with mood regulation, mental health, and selective processing of positive and negative emotional stimuli.

Results: First, the ACE model puts heritability (h^2) of life satisfaction at approx. 33% [Women, 26%, Men 39%]. While important, it suggests the need to revise downwards previous estimates of h^2 = 50%. Preliminary longitudinal modeling suggests that the h^2 of happiness increases with age. Second, we find that **individuals with the transcriptionally more efficient version of the serotonin transporter gene (5-HTTLPR) are significantly more likely to report higher levels of life satisfaction** (p=0.005). Having one or two alleles of the more efficient type raises the average likelihood of being very satisfied with one's life by 8.5% and 17.3%, respectively. We replicate this association on an independent sample (Framingham Heart Study) using the linked rs2020933 SNP. We seek to further replicate this association.

Conclusions: Generally, the importance of integrating the study of genetic variation in order to advance our understanding of the biological underpinnings of individual behavior. Specifically, these results may help explain the important genetic component of the individual baseline levels of happiness.

OFC Value Neurons Do Not have Spatial Tuning

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Objective: Only a limited amount of information is available about the value representation encoded by single neurons in orbitofrontal cortex. There is overwhelming evidence that neurons in this area have an ordered gustatory response to flavors when monkeys must make choices (Tremblay & Schultz, 1999; Kobayashi S, et al., 2010; Padoa-Schioppa & Assad JA, 2008). However, no group has rigorously tested the spatial tuning properties of these neurons. The degree of spatial tuning for movement metrics is of significant importance to the widely discussed hypothesis that these neurons may support choice in an action-independent manner. Here we report a formal test of the hypothesis that OFC neurons have no spatial tuning for stimulus location or action metrics while retaining strong gustatory tuning in a traditional single target visual-saccadic task.

Methods: Macaque monkeys were trained to perform a visually-guided saccade task with stimuli placed at 1 of 81 locations across the visual field spanning the central 32 deg of visual space. Targets were presented in 1 of three colors and each color was consistently associated with one of three juice flavors (apple, grape, orange). To test the spatial tuning hypothesis we fit the measured response fields with three models: i) A global mean firing rate with no spatial structure. ii) A 2-dimensional plane that could be pitched in any direction. iii) A 2-dimensional Gaussian. We used the Akaike Information Criterion to compare the model types.

Results: We separately analyzed all neurons for evidence of spatial tuning. An average of 548 trials spanning the 81 targets crossed with 3 flavors were examined for the most densely sampled group. The Akaike Information Criterion indicates that the mean firing rate model (the model indicating that there is no spatial tuning – not even contralateral preference) is significantly preferred to all other models for more than 90% of the neurons we examined.

Conclusions: This analysis indicates that OFC neurons show no spatial tuning under these conditions; there does not even appear to be a bias for contralateral target representations. These same neurons do, however, maintain a value-related gustatory response even in a task that does not require a choice between targets yielding different rewards. We conclude that the representation encoded by these neurons is appropriate for the participation in a goods-based choice process that could be coupled to previously identified action-based choice mechanisms in the fronto-parietal choice network.

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BOLD Response During Passive Viewing of Stimuli Predicts Subsequent Economic Choice

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Objective: We studied whether brain activity during passive viewing of food images contains information that is predictive of later choices. The study has two objectives. First, does the brain compute value automatically, or are values only computed at the time of choice? We also ask a methodological question: can whole-brain BOLD signals acquired during passive viewing of choice items be used to predict subsequent choices?

Methods: Seventeen hungry subjects passively viewed images of foods during functional imaging. After scanning, the subjects made choices from pairs of the foods shown in the scanner. We extracted the BOLD signals corresponding to each food and used these signals together with subject choices to train a penalized logistic classifier to predict out-of-sample choices from BOLD signals. We used an elastic net (Zou and Hastie 2005) penalty. This classifier both selects predictive voxels, and also allows the contributions of correlated voxels to be averaged. Therefore, it is particularly appropriate for use with fMRI data.

Results: The classification procedure correctly predicted greater than 60% of subjects' choices (between subject average). This average prediction rate is significantly better than chance. On an individual level, prediction rates for a majority of subjects were significantly greater than chance at a 5% threshold.

Conclusions: These results suggest that neural activity during passive viewing contains information that is predictive of future choices. The results provide evidence that the brain automatically encodes components of value, and that these components are both observable and predictive of choices.

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Frontal Asymmetry and Delay Discounting

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Objective: fMRI research indicates that activity in the midbrain reward circuits is associated with preferences for smaller but immediate rewards in a discounting task. There has been comparatively less research, however, on how EEG indicators of reward processing relate to such choices. The EEG frontal asymmetry literature suggests that relatively greater left frontal cortical activity is associated with heightened approach motivation and a stronger engagement with potential rewards. The current study examined whether increased left frontal activity during a delay discounting task would be associated with higher discounting rates.

Methods: Forty-eight undergraduate students participated in the study. EEG was recorded from 32 Ag/AgCl electrodes as participants completed a computerized version of the Monetary Choice Questionnaire, which involves a number of choices between monetary amounts of various sizes and delays. Asymmetry scores were calculated as the difference in log transformed power in the alpha frequency band (8-13Hz) in homologous electrode locations across hemispheres. These scores were then correlated with delay discounting rates, as estimated with logistic regression. A measure of cognitive ability was included to examine its relationship with discounting rates and frontal asymmetry.

Results: Relatively greater left frontal cortical activity, which has previously been associated with heightened approach motivation and the behavioral activation system, was significantly related to higher discounting rates. Individuals displaying increased left frontal activity during the discounting task were more likely to choose the smaller, but immediate rewards. As in previous work, cognitive ability was related to lower discounting rates. However, regression analyses indicated that cognitive ability and frontal asymmetry were independent predictors of delay discounting.

Conclusions: These results suggest that heightened approach motivation (as reflected in greater left frontal activity) is associated with higher levels of delay discounting, consistent with previous individual differences research exploring the roles of extraversion and positive affect. Additionally, these effects were independent of cognitive ability, further emphasizing the role of motivational factors. Finally, the study indicates that EEG may be a useful technique in the investigation of delay discounting processes.

The Effect of Short-term Affective Modulation on Reward Prediction Error Signal: A Study of Feedback-related Negativity

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Objective: Previous study has shown the effect of short-term affective modulation on ERN (error-related negativity) induced by Flanker task. However, whether short-term affective modulation can affect on FRN (feedback-related negativity) remains unclear. The present study applied pictures of IAPS and tested the effect of short-term affective modulation on FRN.

Methods: Eighteen adult subjects participated in the study. The subject received emotional stimuli via pictures of IAPS presented prior to a two-alternative choice based on a non-reinforcement learning task. In which, feedback would be delivered after every choice made. Three blocks, each of 120 trails, were designed with 75%, 50% and 25%, respectively, as the rewarded feedback. Via ERP measurements, LPP (late positive potential) and FRN were extracted during the presentation of pictures and feedbacks, respectively.

Results: As expected, we found that FRN was significant affected by short-term affective stimuli. However, while FRN was significantly reduced by the positive pictures as compared to the neutral ones, there was no significant difference when comparing the negative and neutral ones. LPP examination showed that the largest amplitude elicited by presentation of positive pictures, which indicated a significant arousal involved. FRN amplitudes were found significantly different over the three conditions of reward feedback. Larger FRN amplitude was found when the feedbacks were unexpected to the subject, whereas smaller FRN amplitude appeared when the feedbacks were expected. There was no interaction between different levels of expectancy and pictures valence.

Conclusions: These results suggest that FRN can be modulated by short-term affective stimulation. The subjective arousal level toward affective stimuli might be involved in such a modulatory process.

Preferences During Repeated Visual Probabilistic Choice

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Objective: Humans often make demonstrably sub-optimal choices. One of the most frequently observed errors lies in the representation of probabilities. Here we tested the hypothesis, that a visual representation of probability that does not make use of numerical symbols removes the distortions that plague traditional studies of decision-making.
Methods: We compared human performance in a repeated 'visual choice task' with performance in a traditional 'numeric lottery choice task'; 8 subjects chose between 174 pairs of gambles that differed with respect to probability and assigned outcomes. Probability information was either coded visually by the density of small gray dots displayed on a white background patch or numerically. In both conditions, information about the magnitude of each possible outcome was presented numerically (amount stated in $; outcomes > $0) and through a linear change in the contrast of the dots or the numerals indicating probability. The experiment started with 44 training trials in the visual, and 44 training trials in the numeric choice task. During the visual training period, a scale on the bottom of the screen presented the correspondence between probability and dot density. Subjects chose between the gambles using key presses. Following each choice, the selected gamble was resolved. At the end of the experiment, one of these trials was selected at random for payment to the subject.
Results: We fitted the choice data from all trials, individually for each subject, using a single parameter power utility function, and a one-parameter Prelec probability weighting function with a fixed inflection point of 1/e (and a logit error term). Five of the 8 participants showed reduced probability biases for visually compared to numerically coded probability information. Median response times ranged from 0.76 s to 3 s and did not differ significantly for visual and numeric choices. We tested 2 more participants in a modified version of the experiment, in which visual and numeric probability information was interleaved on a trial-by-trial basis. As before, visual representation reduced the biases compared to numerically coded probability information.
Conclusions: Our results suggest that visual presentation of probability information and repeated execution of the same decision problem facilitate efficient choice strategies that maximize expected utility. We speculate that distinct neural circuits mediate these two kinds of decision-making; an evolutionarily older and more efficient system that is involved in sensory perception and response generation and a more recent and less efficient symbolic system that is accessed by semantic tasks.

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Monetary Reward and Intrinsic Motivation: Neural Basis of Motivation Crowding-Out Effect

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Opposing the widespread belief that people are positively motivated by reward incentives, some studies have shown that performance-based extrinsic reward can actually undermine a person's intrinsic motivation to interesting tasks. This "undermining effect" (also called "motivation crowding-out effect" in the field of economics) not only has practical implications given the burgeoning of performance-based incentive systems in contemporary society, but also presents theoretical challenge for economic and reinforcement learning theories, which assume that monetary incentives monotonically increases motivation. Despite the practical and theoretical importance of this provocative phenomenon, however, little is known about its neural basis. Herein we induced the behavioral undermining effect utilizing a newly-developed task and tracked its neural correlates using functional magnetic resonance imaging (fMRI). Our results demonstrated that performance-based monetary reward indeed undermined intrinsic motivation assessed by the number of voluntary engagement in the task after the reward provision, and that the activity in the anterior striatum and the prefrontal areas decreased along with this behavioral undermining effect. These findings suggest that the cortico-basal ganglia valuation system underlies the undermining effect through the integration of extrinsic reward value and intrinsic task value. We conclude by urging researchers to incorporate the concepts of intrinsic motivation into neuroscience, as most neuroscience research on motivation to date has been confined to extrinsic rewards such as food or money.

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Discounting Time and Probability by Perception of Reward

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Objective: A common finding in studies of temporal and probability discounting is that the rate at which future or uncertain rewards are discounted depends on the magnitude of the delayed or uncertain reward. In temporal discounting, large rewards are discounted at a lower rate than small rewards (the magnitude effect), while for probability discounting, larger rewards are discounted at a greater rate (the reverse magnitude effect). Together, the magnitude and reverse magnitude effects have been cited as evidence that separate processes underlie the two forms of discounting. We describe a new model of decision-making, the Recursive Hyperbolic model (RHM), which suggests a common mechanism for both temporal and probability discounting.

Methods: The RHM was fit to published data (*1*) in which human participants indicated preferences for choices involving delayed or probabilistic rewards with two different reward levels. Additional simulations investigated the effect of parameter manipulation on discounting behavior.

Results: Parameters for the RHM were found which accurately captured both the magnitude and reverse magnitude effects observed in human choice. Notably, both temporal and probability discounting were described by a single parameter set. In contrast, previous models of discounting behavior (e.g., hyperbolic discounting) require a separate set of parameters for each reward level. Further simulations suggest that manipulation of a single parameter in the RHM model related to perception of reward produces a pattern of change in discounting behavior consistent with individual differences related to impulsivity. We relate these results to evidence which suggests that dysfunction of the serotonergic system may partially contribute to impulsive behavior.

Conclusions: We present a new model of decision making which suggests a common mechanism, perception of reward, underlies both probability and temporal discounting. The model provides a convenient theoretical framework for studying rewards which are both delayed and uncertain, and provides a novel interpretation of the effects of impulsivity on choice behavior. Furthermore, the existence of a single mechanism subserving both delay and probability discounting suggests both kinds of decision making may share a common neural substrate, and may provide critical insight into the function of neuromodulatory systems implicated in impulsive behavior (e.g., serotonin).

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Normalized value coding underlies irrational choice behavior

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The neural circuits underlying decision-making must represent the values of the available choice options. In the monkey lateral intraparietal area, neural activity is strongly modulated by the value of specific saccades. In recent neurophysiological experiments, we have demonstrated that this value representation is not absolute: neurons code the value of saccades to the response field relative to the values of all available saccade choices. This value normalization is well-described by a divisive normalization model that also characterizes nonlinear phenomena such as gain control and cross-orientation suppression in visual cortex.

Does this normalized value representation affect behavior? We explore here the predictions of the normalization model and compare them to observed choice behavior. Computational simulation of the choice process indicates that normalized value coding produces a specific violation of rational choice theory: preference between two high-valued options appears to be a function of a third, low-valued irrelevant alternative. This effect depends crucially on cortical neuron response variability: as the total value of available options increases, the separation between the distributions of firing rates representing two differently valued options decreases; if variance does not decrease appropriately, the options will be increasingly difficult to distinguish.

We examined the predictions of the divisive normalization model in both human and non-human primates. We trained two monkeys to choose between three differently valued stimuli (A, B, and C). Stimulus locations and reward associations were fixed within a block; across blocks, the values of the target options (A and B) were varied to quantify how choice varied as a function of value difference. The distractor option (C) provided one of two possible values, which was always lower than any possible target option value. We find that choice is context-dependent: the relative preference between two high-valued options depends on the value of the third option. At low distractor value, monkeys are more likely to correctly choose the better target option; at high distractor value, choice behavior becomes more stochastic. Importantly, this effect is equivalent to a change in the slope of the logistic choice function, an effect predicted by the combination of normalized value and cortical variability. Consistent with a localized cortical mechanism, this context dependence is spatially modulated, exhibiting a stronger effect when the distractor and target options appear in the same visual hemifield. Furthermore, preliminary studies examining human choice behavior in an analogous task show similar results. We conclude that the normalized representation of value in choice circuits is observable at the behavioral level, and may play a role in real-world examples of context-dependent choice.

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Individual Variance across Probability Discounting, Reversal Learning, and Working Memory in Rats

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Objective: Decision making is a complex process that requires skill in several cognitive realms, including learning, memory, cognitive flexibility, value detection and comparison, and action selection. Although many decision-making studies address other forms of cognition, it remains unclear what underlies individual variance on typical decision-making tasks.

Methods: We examined whether individual variance among Sprague-Dawley rats on a discounting decision-making task correlates with individual variance on memory and cognitive flexibility performance. Each task is conducted on an automated Figure-8 maze (cf., Graham et al., 2010). To assess decision-making ability, we used a probability-discounting task, in which animals choose between small/certain and large/uncertain rewards. The larger, uncertain reward had an expected value either 50% higher or 50% lower than the smaller, certain reward during "Uncertain Bias" and "Certain Bias" conditions, respectively. Over several days of exposure to each bias condition, rats biased their choices toward the reward with the higher expected value We further evaluated decision-making performance based on two variables: risk preference (average preference of the large reward under high and low probabilities) and discrimination (the difference in preference of the large reward between high and low probabilities). We correlated individual performance across several measures to determine whether individual variance in performance on a probability-discounting task could be explained by variance in either working memory or cognitive flexibility.

Results: Probability discrimination did not correlate with individual risk preference. Accuracy on a delayed alternation working memory task negatively correlated with probability discrimination, but was unrelated to individual risk preference. Reversal learning performance positively correlated with risk preference, but not discrimination, on the probability-discounting task. However, a different measure of cognitive flexibility, the rate of response following a probability shift, did not correlate with either discrimination or risk preference.

Conclusions: The cognitive processes required for probability discrimination on a decision-making task may be related to those required for working memory performance, and risk preference may modulate reversal learning performance. Probability discrimination and risk preference both vary among individual rats and are distinct measures of decision-making cognition. It remains unclear whether they represent lower-level forms of cognitive processing that subsequently influence other higher-order tasks (e.g. working memory, reversal learning) or whether there may be additional factors that simultaneously influence each of these particular measures of performance.

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BOLD correlates of evidence integration during value-based decision making

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Objective: Influential theories of choice posit that decisions are generated following an integration of evidence about different decision options. The aim of the present research was to determine whether evidence accumulation occurs in the brain during value-based decision making, and to identify the brain regions exhibiting this response profile. Additionally, we were interested in comparing different classes of accumulatory models in order to see which class better reflects neural signals.

Methods: Here we used fMRI to measure BOLD signals while 20 hungry subjects made decisions between pairs of food items which could be consumed later. On each trial options were shown in a repeated serial fashion until an item was selected. After completing the choice section, participants then provided buying prices and familiarity ratings for each of the food items and upon completion of the experiment were given up to two foods to consume, depending on both random selection and their preferences. We applied a variety of computational models of decision making that posit different types of evidence accumulation to the fMRI data and tested for regions showing correlations with the accumulation process engendered by these different models during choice. Mean predicted signal per trial was obtained by simulating the models using the best fitting parameter values. This mean predicted signal was then regressed on the BOLD data, separately for each model.

Results: The results revealed that multiple regions correlated with the model predicted accumulation signals, including regions of the posterior parietal cortex, dorsolateral prefrontal cortex, and ventromedial prefrontal cortex. The different model classes revealed both overlapping and unique activation areas.

Conclusions: These results can help to disentangle the specific computations performed by different brain regions during decision making as well as provide evidence concerning which class of model can better explain neural activity during value-based decision making.

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Title: Shockingly conservative: Threat of shock increases risk aversion

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Abstract:
Emotions have important roles in decision behavior as demonstrated by evidence both from studies that illustrate the influence of nominally irrelevant emotional manipulations upon choices, as well as those that show correlations of emotional variables with decision-making. In one example of the latter, a recent study showed that the relative physiological arousal responses to gain and loss outcomes correlated with individuals' estimated loss aversion (Sokol-Hessner et al, 2009). However, because arousal was not experimentally manipulated, any conclusions from these data are limited to statements of correlation. In order to move beyond such limitations, in this study participants faced a similar series of monetary choices in one of two contexts: "Threat", in which participants experienced intermittently reinforced auditory conditioning with a tone predicting electric shock, and "Safe", in which neither tone nor shock was present. Conditioning is a robust and well-characterized technique for eliciting discrete arousal responses, similar to those observed during the decision task in Sokol-Hessner et al (2009). Beyond the unique introduction of a shock-based conditioning paradigm, a three-parameter model of participants' choice behavior was also quantitatively estimated from individuals' choices, enabling improved specificity in isolating effects of the manipulation on behavior, as compared to previous studies. The threat of shock was found to systematically bias individuals' behavior such that they demonstrated increased risk aversion, relative to their choices made not in the presence of shock, and this effect could be distinguished from changes in loss aversion or individuals' consistency over choices. By combining conditioning with econometric models of decision behavior, these results contribute strongly to our understanding of how emotional arousal may causally affect the choices we make.

Chronic marijuana use is associated with distinct neural activity during monetary decision-making

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Objective. Marijuana (MJ) acutely acts on cannabinoid receptors that are found in numerous brain regions including those involved in reward processing and decision-making. However, it remains unclear how long-term, chronic MJ use alters reward-based decision-making. In the present study, using [^{15}O]water PET imaging, we measured brain activity in chronic marijuana users (CMJUs) and non-using control participants while they took part in the Iowa Gambling Task, a monetary decision making task that strongly relies on a neural circuitry in which the ventromedial prefrontal cortex is a key component for implementing advantageous decision-making.

Methods. Forty-six CMJUs and 34 control participants took part in the study. During PET imaging, participants took part in the standard version and a control version of the Iowa Gambling Task, as well as other tests. In the standard version of the task, participants must choose from one of four decks of cards. Participants learn through trial and error that two of the decks are advantageous (gains outweigh losses) and two are disadvantageous (losses outweigh gains). The task was timed so that the primary learning phase (trials 11 – 50) coincided with PET image acquisition. The control version of the task did not require decision-making; participants simply chose from each of the four decks in a pre-determined sequence.

Results. CMJUs and control subjects showed a great deal of common activity in regions involved in reward processing and decision-making, including the ventromedial prefrontal cortex and anterior cingulate cortex. In the two-group comparison, CMJUs did not show lower activity in the ventromedial prefrontal cortex as expected; in fact, using a more liberal threshold, CMJUs showed higher activity in this region. CMJUs also showed higher activity than control subjects in the cerebellum. Finally, greater duration of MJ use was associated with lower task-related activity in the anterior cingulate cortex.

Conclusions. CMJUs tend to rely more heavily on neural circuitry involved in decision-making and reward processing (ventromedial prefrontal cortex) and probabilistic learning (cerebellum) possibly reflecting inefficient information processing within these regions. Furthermore, given that duration of MJ use was associated with lower activity in the anterior cingulate, a region implicated in attention and error detection, chronic MJ use may alter the ability to modify decision making based on unexpected patterns of rewards and punishments.

Acknowledgments:
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Effector-Specific Reward Value Updating in the Posterior Parietal Cortex

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Objective: To make effective decisions we must first learn then update the values of the objects under consideration. How we learn values and then make choices for different effectors poses an interesting question. We tested the hypothesis that a single decision system guides choices for multiple effectors or alternatively whether separable systems guide choices for different effectors.

Methods: Two adult Rhesus macaques were trained to perform a variant of a two armed-bandit task. Animals chose between two targets each associated with a different reward value. Choices were made with either a single effector (reach-only, or saccade-only), or with two effectors (reach-and-saccade). The effector used on each trial was interleaved randomly, however the reward distributions of the two targets was kept constant across trials allowing the reward values to be learnt from either effector. The mean of the reward distributions were kept consistent for 50-60 trials after which were changed in an unsignaled manner. Individual neurons were recorded from the posterior parietal cortex as the animals performed this task. Seventy neurons were recorded from the posterior reach region (PRR), an area active before reaches and 47 neurons from lateral intraparietal area (area LIP), an area active before saccades.

Results: Firing rates of neurons in both area LIP and PRR were modulated by reward values however area LIP showed stronger modulations than PRR. Choice selectivity emerged significantly faster in area LIP (579±41 ms) than PRR (691±29 ms, (mean±s.e.m) p=0.04; Rank Sum test). When comparing the build up of choice information before and after the reward transition, PRR showed a significant slowing of the build up after the transition which we attribute to the learning of the new reward values. This difference was not seen in area LIP indicating differences in how reward values are updated in the two areas. To analyze how the animals learned reward values from rewards received from different effectors, a model that explained choices as a linear combination of previous rewards was fit. This model showed that a higher waiting was given to rewards received on trials in which a saccade was involved.

Conclusions: These results suggest that separate value updating rules may be applied to rewards received from different effector movements and that separable decision systems may guide movements for different effectors.

Acknowledgements: This study was funded by the NSF-NIH CRCNS MH087882, Alfred P Sloan Foundation, McKnight Foundation, Burroughs Wellcome Fund, and NYSTAR.

A Neural Substrate of Probabilistic and Intertemporal Choice Within a Single fMRI Experiment

Hiroyasu Yoneda [*†‡] Sobei H. Oda [§]

Objective: The purpose of our study is to investigate differences and similarities in brain activities between choice under uncertainty and intertemporal choice. Some researchers have found that risk preference are correlated strongly with delay preference across individuals; others claim that the correlations are weak or absent. We did an fMRI experiment to examine risky choice and intertemporal choice within the same framework.

Methods: Twenty one subjects participated in our study. In an MRI they were repeatedly asked two-option questions (90 questions for each subject). Three conditions were used in the task: Delay tasks (choices between future and present/nearer future rewards) Risk tasks (choices between risky and certain/less risky rewards) and Control tasks (trivial delay or risk tasks).

Results: We found that precuneus and parahippocampal gyrus were activated more when they chose a future reward (1 or 2 weeks later) than they were when an uncertain alternative (40% or 80%) is chosen. In contrast, Orbitofrontal cortex (OFC) and angular gyrus were activated more when they chose a uncertain alternative than they were when an future reward is chosen.

Conclusions: Together with other observations, our results support, at least is consistent with, the self-projection theory proposed by Buckner and Carroll (2006): people imagine future themselves to choose a future reward. In addition, we examined our subjects' brain activities according to their preferences: certainty preference, risky preference, early-reward preference, and delay-reward preference, which give other evidences to support the theory.

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Working Memory and Intertemporal Choice

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Abstract: Intertemporal choice (ITC) involves trade-offs between costs and benefits at different points in time. Recent neuroimaging data suggest that ITC involves a dynamic interplay between brain regions associated with cognitive control and working memory (WM), such as prefrontal cortex, and structures in the limbic system associated with the evaluation of reward. Here we test the hypothesis that engaging participants in an unrelated task that competes for the cognitive control mechanisms of WM during ITC should lead to more impulsive decision-making. Previous research on the effect of WM load on ITC is inconclusive on this point because it has been difficult to distinguish impulsive from random responding (Franco-Watkins, Pashler, & Rickard, 2003; Hinson, Jameson, & Whitney, 2003). Participants in this experiment made ITC decisions while simultaneously performing an n-back task under high load (3-back) or low load (0-back). A stair-casing method was used to determine each individual participant's indifference point and subsequent choice values were titrated around this point. Participants in the high load condition chose the sooner reward more often than those in the low load condition and participants in both groups demonstrated a reliable pattern of responding around the indifference point. These results support the conclusion that WM working memory load results in more impulsive decision-making.

Neural Correlates of Cognitive Dissonance and Choice-Induced Preference Change

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Objective: While economic theory views that actions are simply reflective of individuals' preferences, a psychological theory claims that actions can create preference. According to the cognitive dissonance theory, after making a difficult choice between two equally preferred items, the act of rejecting a favorite item induces uncomfortable feeling called "cognitive dissonance," which in turn motivates individuals to change their preferences to match their past decisions (i.e., reducing preference for rejected items). However, neural processes underlying dissonance-induced preference change remain largely unknown. We conducted an fMRI experiment to examine how subjects' preferences for the same foods changed after making difficult choices between two preferred foods and also how the brain responds to cognitive dissonance (i.e., discrepancy between their past decisions and preferences).

Methods: Images of one hundred sixty food items (e.g., chips, chocolate, etc) were used in the experiment. The experiments consisted of four parts; 1) Preference task 1, 2) Choice task, 3) Preference task 2, and 4) Post-Experimental Choice task. Except for the Post-Experimental Choice task, all tasks were performed during fMRI scanning.

Results: We first found that subjects' reported preferences during the Preference task 1 were positively correlated with the activity in the anterior striatum. Then, as predicted, the striatal activity was significantly reduced from the Preference task 1 to the Preference task 2 for the preferred foods which were rejected during the Choice task compared to other control conditions. Furthermore, we found that the dorsal anterior cingulate cortex (dACC) and dorsolateral prefrontal cortex (DLPFC) tracked the degree of cognitive dissonance on a trial-by-trial basis.

Conclusions: This study provides evidence that the mere act of making choices can alter individual's self-report preference as well as its neural representation, and dissonance-induced preference change recruits the same neural network underlying the monitoring of lower level conflict and the subsequent implementation of control.

Acknowledgements:
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Rats respond to the opponents' change in strategy in a competitive game

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Objective: We studied whether Wistar rats were capable of playing the Matching Pennies game (MPG), and how they responded to the use of different strategies by a computer opponent. MPG is a simple strategic game, in which players' choices, to be optimal, must be independent of previous choices and payoffs. According to reinforcement learning models, adjustments of choice policy are based on discrepancies between expected and obtained rewards, thus generating more predictable choice sequences, which lead to a lower reward rate.

Methods: Eleven male Wistar rats were trained to play a nose-poke version of the game. In each trial, after nose poking a central hole, they had to choose one of two lateral holes. When the animal and the computer chose the same hole, reward (sucrose solution) was provided. The computer was programmed to use two different algorithms to predict the animals' next choice, and thus exploit eventual biases in their choice sequence. The first algorithm ONLY exploited statistical biases present in the right (R)-left (L) choice sequence, e.g. the probability of L choice after a RRL sequence. So, a reinforcement learning policy of repeating rewarded choices was not penalized. In the second algorithm, the sequence of choices and the payoffs was taken into account, e.g. the probability of a R choice after a R(+)R(-)L(+) sequence (where (+) and (-) stand for rewarded and unrewarded choices, respectively). Consequently, in the second algorithm, the probability of getting rewarded was smaller when subjects used the "win-stay-lose-shift" strategy (WSLS). Therefore, if rats were sensitive to the opponents' strategy, their probability of using a WSLS in the second algorithm would be smaller.

Results: When playing against algorithm 2, subjects used WSLS significantly less than when playing against algorithm 1 (Wilcoxon signed-rank test, $p=0.002$). There was no significant difference in the reward rate (Wilcoxon signed-rank test, $p > 0.05$), which was 48%, significantly different from the expected optimal rate of 50% (Wilcoxon signed-rank test, $p = 0.0001$).

Discussion: Rats were capable of approaching the optimal strategy in the MPG, and were sensitive to changes in the opponent's strategy, responding accordingly. The changes in the probability of WSLS and the lower reward rate, demonstrate that reinforcement learning is at the core of the animals' strategy.

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Exposure to Economic Arguments Reduces Delay Discounting

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Objective
When making decisions that involve tradeoffs between the quality and timing of desirable outcomes, people consistently discount the value of future outcomes. Discounting is often measured in the laboratory using monetary rewards, by asking subjects to choose between a smaller amount of money available immediately and a larger amount available after a delay. The high degree of discounting observed on this task is extremely puzzling to many economists. For decisions about money, a normative argument can be made that regardless of personal time preferences, subjects should only turn down rates of return from the experimenter that are lower than rates available to them elsewhere, such as on the market. However, all studies of delay discounting cite monetary discount rates that are orders of magnitude higher than market interest rates. Here we ask whether one reason that subjects discount to such a degree is that they are simply unaware of the normative argument or how it applies to the task.

Methods
Subjects read a "financial education guide," which explicitly outlined the normative argument with concrete examples. Each subject completed a monetary delay discounting task with real financial incentives at three time points: before, immediately after, and one month after reading the guide. When returning one month later, subjects' sessions were run by a different experimenter, with no mention made of the material read at the previous session.

Results
Immediately after reading the guide, discount rates decreased significantly. One month later, discount rates had increased, but remained significantly lower than before subjects had read the guide. This decrease was not due to subjects adopting simple decision rules, such as setting a cutoff amount or always selecting the later reward. Rather, subjects appeared to integrate the information from the guide and adjust their degree of discounting.

Conclusions
These results demonstrate that one reason for high monetary discount rates is that subjects have not considered relevant economic arguments, although other factors (i.e., liquidity constraints, uncertainty regarding payment) are also needed to fully explain the deviation from market interest rates. These results also show how a simple educational intervention can have a significant and long-lasting effect on decision-making. As such, this paradigm should prove useful for studying the neural mechanisms by which education can change behavior. Ongoing experiments are examining this question.

Subliminal Brand Priming Influences Incidental Decision-Making

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Objective: In the present study we examined incidental effects of brand presentation on financial decision-making. We explored the possibility that brand images with affective value impact on decisions by influencing affective systems underlying decision-making.

Methods: Sixteen participants attended a behavioural session and a subsequent fMRI session. Participants performed a temporal discounting task (see Kable & Glimcher, 2005), and a perceptual direction task (control). In the temporal discounting task, half of the choices were subliminally primed (16ms, pre- and post-masked) with an affective image ("Apple" logo), half with a neutral image (cup). We then used multivariate pattern classification to predict different aspects of decisions for each stimulation group separately from local spatial brain activation patterns, using an unbiased, moving "searchlight" (Kriegeskorte et al., 2006; Haynes et al., 2007). Additionally, we used univariate analyses to search for brain regions in which activation was directly modulated by subjective values of choices in each trial.

Results: The behavioral experiment demonstrated that priming with the subliminally presented "Apple" logo shifted participants' choices relative to the neutral condition. Multivariate pattern classification showed that activation patterns in orbitofrontal cortex (OFC) predicted the general task type (temporal discounting vs. control). We could further predict which subliminal prime was used within the temporal discounting condition from activation patterns in anterior cingulate cortex (ACC) / medial prefrontal cortex (PFC). Decision outcomes (now vs. later) were also differentially encoded for each priming group, with predictive patterns in OFC / medial PFC for "Apple" and inferior parietal lobe for "neutral" (cup). Univariate analyses showed that for the temporal discounting task, activation in striatum, dorsolateral PFC and ACC was correlated with subjective value of the choice.

Conclusions: We could show a subliminal priming effect of an emotionally-relevant stimulus on an unrelated temporal discounting task. The stimulus seemed to modulate valuation of the incidental reward, as indicated by differential activation patterns in brain regions previously implicated in valuation (striatum, medial PFC). Overall, subjective values were directly reflected in activation in brain areas, which are part of a network underlying temporal discounting and, more broadly, affective learning and decision making processes (Kable and Glimcher 2007; McClure et al. 2004; Singer et al. 2009).

Frontopolar cortex contributes to choice exploration by tracking recent payoff trends

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Objective: The functions of frontopolar cortex (FPC) have long been enigmatic. Recent neuroimaging studies find that it is activated during exploring and switching in the tracking of variable rewards during n-armed bandit tasks, but leave unresolved its causal contributions to behavior. We examined the ability of patients with brain lesions that include frontopolar cortex to track variable payoffs in a 4-armed bandit task previously shown to elicit BOLD activity in FPC.

Methods: 6 patients with lesions encompassing FPC (FP group), 8 brain-damaged comparison subjects whose lesions spared FPC (BDC group), and 14 normal comparison subjects (NC group) participated in a 4-armed bandit task for a fictive monetary reward. Mean payoff generated by each bandit followed a random walk. Subject choices were fitted to two different models: (1) a multinomial logistic (MNL) model in which the predictor was the history of the previous 5 payoffs for each bandit, (2) a reinforcement learning model augmented with the difference between the last two payoffs (RL+LD). Responses from each subject were fitted to both models. Maximum likelihood parameter estimates were compared for each group using non-parametric statistics.

Results: Significant group differences were observed in the lag-1 (Kruskall-Wallis $P = 0.035$) and lag-2 ($P = 0.065$) regression weights under model 1. Of note, NC subjects showed a negative weighting on the lag 2 payoff (Wilcoxan rank-sum $P = 0.025$), which contradicts the geometric weighting predicted by an RL model. We hypothesized that the negative lag-2 weight reflected a tendency to extrapolate trends. We therefore fitted an RL model augmented with a linear dependence on the difference between the last two payoffs (RL+LD). Groups showed no significant difference in the parameters of the RL component (learning rate: $P = 0.45$, softmax temperature: $P = 0.65$), whereas the group effect for the LD term was significant ($P = 0.0067$). Post-hoc tests revealed that BDC and NC groups significantly weighted the lag-difference ($P = 0.0017$ and $P = 0.016$, respectively), whereas FP subjects did not ($P = 0.56$). FP subjects differed from NC and BDC (Tukey's HSD, $P = 0.051$ and $P = 0.0050$, respectively), while NC and BDC groups did not differ ($P = 0.43$).

Conclusion: Using model-based analyses of choice behavior in patients with focal brain lesions, we show that the frontopolar cortex makes a specific contribution to exploratory behavior: extrapolating current trends from comparisons among the most recent outcomes. Moreover, the contributions of trend following and reinforcement learning to choice valuation are functionally dissociable.

Saturday, October 16, 2010

Lunchtime Presentation

Grand Parlor CD

Federal Funding Opportunities for Neuroeconomics: A Roundtable Discussion with NIH and NSF Program Officers

Understanding the neurobiological underpinnings of decision making has significant potential to inform public health and public policy. This roundtable presentation will feature brief presentations on neuro-economics-related grant opportunities by program officials from the National Institutes of Health and the National Science Foundation. This will be followed by an extended Q & A session on potential grant application strategies for the respective federal agencies.

James M. Bjork, Ph.D.
Program Official, Clinical Neuroscience Branch
Division of Clinical Neuroscience and Behavioral Research
National Institute on Drug Abuse
National Institutes of Health

Lis Nielsen, Ph.D.
Program Director, Division of Behavioral and Social Research
National Institute on Aging
National Institutes of Health

Jonathan W. Leland, Ph.D.
Program Director, Decision, Risk and Management Sciences
Division of Social and Economic Sciences
National Science Foundation

Nancy A. Lutz, Ph.D.
Program Director, Economics
National Science Foundation

Saturday, October 16, 2010

Abstracts for Session III

Affect & Liking

Chair: Nai-Shing Yen

9:00 – 9:20 am	Katia M. Harlé	The neural basis of mood-driven biases in social economic decision making	K.M. Harlé, L.J. Chang, M. van't Wout and A.G. Sanfey
9:25 – 9:45 am	Kaisa Hytönen	Path-dependence in risky choices: role of affect and cognitive control	K. Hytönen, A. Smidts, G. Baltussen, M.J. van den Assem, V. Klucharev, and A.G. Sanfey
9:50 – 10:10 am	Gregory Berns	A neural predictor of cultural popularity	Gregory S. Berns and Sara E. Moore

The Neural Basis of Mood-Driven Biases in Social Economic Decision-Making

K. M. Harlé,[1*] L.J. Chang[1], M. van't Wout[2] and A.G. Sanfey.[1,3]

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Objective: The neural mechanisms mediating the impact of emotion on decision-making remain to a large extent unexplored. However, empirical evidence suggests that even incidental affect (i.e. emotional states *unrelated* to the decision at hand) can bias decision-making. Based on previous behavioral findings showing that induced emotional states (i.e. sadness and disgust) can alter simple economic decisions within a social context, we investigated the neural basis of such decision biases.

Methods: Nineteen adult participants made decisions which involved accepting or rejecting monetary offers from human and non-human (computer) partners in an Ultimatum Game, while undergoing functional magnetic resonance imaging (fMRI). The partners' offers consisted of proposals to split an amount of money between the two players, ranging from $1 to $5 on each offer (from of a $10 pot). Prior to each set of decisions, participants watched a short video clip aimed at inducing either sadness or a neutral emotional state.

Results: Participants in the sadness condition rejected more "unfair" (i.e. $1-$3) offers than those in the neutral condition, replicating our previous behavioral findings. Neuroimaging analyses revealed that receiving unfair offers while in a sad mood elicited activity in brain areas related to aversive emotional states (insula) and cognitive conflict (anterior cingulate cortex). In contrast, no neural correlates of sadness were observed during phases preceding offer proposal or when participants received "fair" offers ($5). Results further suggest that insular activation upon receiving unfair offers may mediate the negative relationship between sadness and acceptance rates of these types of offers.

Conclusions: These findings suggest that a sad mood may selectively engage neural regions involved in affective processing (e.g. insula) and lead to decision biases within specific mood-congruent contexts.

Path-dependence in risky choices: role of affect and cognitive control

K. Hytönen[1,3], A. Smidts[1], G. Baltussen[2], M.J. van den Assem[2], V. Klucharev[1,3], and A.G. Sanfey[3,4]

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Objective: Decision-makers' risk attitude generally depends on the outcome of previous choices. That is, decision-makers tend to make riskier decisions both if they have a chance to win back a previously experienced loss, the break even effect (BEE), and if they can gamble with previously won money, the house money effect (HME). Previously these effects have been explained by insufficient updating of a reference point: after a positive outcome, the reference point is low decreasing the influence of loss aversion in future choices, whereas after a negative outcome the reference point is high leading to risk seeking attitude which is predominate in a loss domain. Here we propose and test another possible explanation: the changes in risk-appetite after gains and losses may be driven by single or multiple affective mechanisms.

Methods: We conducted a functional magnetic resonance imaging study using a sequential choice paradigm where subjects systematically show the two behavioral effects. Our paradigm enables us to compare choices after previous gains, losses and neutral outcomes while controlling for other variables in the choice problems.

Results: Both relative gain and loss experiences activated an overlapping anterior insula (AI) – rostral anterior cingulate (ACC) network, brain areas which have previously been related to affect and arousal. Simultaneously, relative gains and losses deactivated the dorsal stream, reflecting decreased use of cognitive control mechanisms. Interestingly, ACC activity also predicted future lottery choices, in line with the increasing risk-appetite after gains and losses. Further, the AI activity correlated with the strength of behavioral effects in two different time windows. First, activity during loss experience correlated negatively with BEE in future choices. Second, during the following choice after a gain experience, AI activity correlated negatively with HME. These findings suggest that high level of affective arousal during loss experiences might decrease the future risk appetite in stead of increasing it in line with BEE. In contrast, high levels of arousal during a choice after a gain might decrease HME, possibly reflecting the high level of fear for losing the previous gain.

Conclusions: The results show that both gain and loss experiences activate a common arousal related network and deactivate the cognitive control network, suggesting that the increase in risk-appetite might be influenced by affective mechanisms. However, particularly high levels of arousal may lead to decreased risk-appetite, suggesting that the high levels of affective arousal might guide choices towards more rational choice patterns.

A Neural Predictor of Cultural Popularity

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Objective: What determines whether something or someone achieves widespread cultural popularity? Previous research has demonstrated the link between individuals' neural responses to goods and subsequent purchase decisions by those individuals. Here, we show that such responses generalize to the population at large and can be used to predict the widespread success of a particular good: music.

Methods: 32 adolescents (12-18) participated in the study from October 2006 to August 2007. While in the MR scanner, subjects listened to 15-sec clips of songs downloaded from myspace.com. 20 songs were previously selected from each of 6 genres of unsigned or independent artists. Each participant heard 60 songs from their favorite 3 genres. They rated songs for likability and familiarity and received a CD of their top-rated songs. To measure the success of each song subsequent to the scan period, the total number of units sold (individually and the album) through May 2010 was retrieved from Nielsen Soundscan, which is the industry standard for calculating Billboard ranks. After standard preprocessing, a three-level analysis of the songs was performed. First, the listening period for each of the 60 songs was modeled separately, for a total of sixty 15-sec variable duration events. Second-level models for each of the 120 songs were constructed as one-sample t-tests in SPM5 using contrast images from the first-level model. Since every participant did not hear every song, the number of contrast images in each of these second-level models ranged from 3 to 23. A third-level model, also a one-sample t-test, was built from the positive contrast images from the second-level model. This model included a covariate of the likability rating for each song, averaged over the participants who heard that song. Regions extracted from the modulated contrast were then correlated with the number of units sold of each song.

Results: From the third-level model, the ventral striatum [9 6 -9] was significantly correlated with the average likability of each song (30 voxels, $P<0.001$). The log-transformed number of units sold was also significantly correlated with the average activation within this ROI ($R=.31$, $P=0.004$).

Conclusions: These results suggest that the neural responses to goods are not only predictive of purchase decisions for those individuals actually scanned, but such responses generalize to the population at large and may be used to predict cultural popularity.

Acknowledgements:
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Saturday, October 16, 2010

Abstracts for Session IV

Social Decision Making

Chair: Kevin McCabe

10:45 – 11:05 am	Corey McMillan	The neural basis for establishing a focal point in pure coordination games	C.T. McMillan, M.C. Khella, K. Rascovsky, R. Clark, and M. Grossman
11:10 – 11:30 am	Dongil Chung	Neural predictors and spatiotemporal dynamics of free-riding	Dongil Chung, Kyongsik Yun, Jaeseung Jeong
11:35 – 11:55 am	Ernst Fehr	The neuroeconomics of social norm compliance	Ernst Fehr

The Neural Basis for Establishing a Focal Point in Pure Coordination Games

C. T. McMillan[1*], M.C. Khella[1], K. Rascovsky[1], R. Clark[2] and M. Grossman[1]

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Objective: Pure coordination games require players to establish a Nash equilibrium when there is no way of distinguishing one equilibrium from another. Mehta (1994) demonstrated that individuals use focal points to coordinate with another individual. For example, when probed for a boy's name participants provided the response "John" (9%) less often than when instructed to coordinate a boy's name with an anonymous partner (50%). However, little is known about the neural mechanisms that support coordination. We hypothesize that coordination is supported by ventral medial prefrontal cortex (vmPFC), a region commonly implicated in perspective-taking and in executive resources such as mental flexibility. Behavioral variant frontotemporal dementia (bvFTD) patients have a neurodegenerative disease that compromises vmPFC. These patients exhibit a disorder of social comportment and have limited executive resources.

Methods: We presented 9 bvFTD patients and 9 healthy seniors (HS) with 12 questions probing a semantic category (e.g., "Tell me a boy's name") in two conditions. In the survey condition participants were instructed to provide any response. In the coordinating condition participants were told that their responses were going to be paired with an anonymous participant and were instructed to give a response that would match their partner's response. We calculated a latent semantic index value (LSI; Landauer, 1998) for each response relative to the category name to quantify the semantic typicality of each response: a low value represents less semantic typicality (e.g., boy-Ricky) and a high value represents greater semantic typicality (e.g., boy-John). We used voxel-based morphometry (VBM) to quantify cortical atrophy in a subset of bvFTD patients (n=6) and we related this atrophy to task performance using a multiple regression analysis.

Results: HS changed their responses from the survey to the coordinating condition more often than bvFTD [$t(16)=3.86$; $p<0.005$]. A comparison of the LSI values in the coordination response relative to the survey response revealed that HS provided responses that were more semantically typical when coordinating than bvFTD [$t(16)=2.38$, $p<0.05$]. The VBM analyses revealed that bvFTD have significant atrophy bilaterally in vmPFC and there was a significant relationship between atrophy in vmPFC and the amount that bvFTD coordinated.

Conclusions: Together, these results establish that bvFTD have limitations with coordination which may be related to poor perspective-taking or limited mental flexibility. This limitation is associated with vmPFC atrophy and we propose that vmPFC supports the process of establishing equilibrium in pure coordination games.

Acknowledgements:
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Neural Predictors and Spatiotemporal Dynamics of Free-riding

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Objective: Maintaining a stable and efficient allocation of public goods (PG) over a long-term period is a critical issue that is currently being addressed in multiple fields. Although the cognitive motivations underlying free-riding and cooperation in decision-making have been studied, neural process of the regarding information on strategic decision-making is still unrevealed. The current study searches for neural predictors of free-riding and cooperation using EEG recordings.

Methods: We used an iterative, binary PG game that simulates free-riding behavior within social interactions. Sixty-five healthy male participants were recruited for the study, and EEGs were recorded from twenty-six participants during the game (two randomly selected participants per group). We analyzed EEG signals after indicating whether the preceding trial was a success or failure and after revealing the number of cooperators in the preceding trial, examining the neural response to each piece of information and investigating whether features of the EEG signal predicted subsequent free-riding and/or cooperation decisions.

Results: The amount of money the participants earned in each trial was negatively and significantly correlated with activity in frontal lobe. Prediction errors regarding the number of free-riders in each trial were also encoded in frontal and temporal lobes. Activity in anterior and dorsal frontal regions predicted the subject's decision-making over 80% of the time and may provide a neural predictor of free-riding and cooperation.

Conclusions: These findings suggest that the cognitive processes underlying free-riding and/or cooperative behavior are processed separately but in parallel with information regarding previous results. A spatiotemporal analysis of the neural predictors of free-riding might reveal the complex and context-dependent motivations for free-riding.

Acknowledgements:
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The Neuroeconomics of Social Norm Compliance

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All known human societies establish social order by punishing cheaters and norm violators. In recent years, neuroeconomists have discovered important components of the neural circuitry underlying human norm obedience and norm enforcement. The lecture will document that the prefrontal cortex - a brain area particularly well developed in humans - is key in this human ability. Non-invasive down-regulation of neural activity in prefrontal cortex reduces norm compliance despite the fact that individuals are still able to distinguish between "right" and "wrong". Neuroeconomic research on young children - whose prefrontal cortex is not yet well developed - shows similar patterns. These results thus indicate a dissociation between the ability to obey social norms and the knowledge of the content of the social norms, which complicates the attribution of responsibility for norm violations.

Poster Session II: Saturday 1:30PM - 3:30PM		
#	Title	Authors
1	Behavioral and Neurobiological Evidence for Probabilistic Sophistication	Mathieu d'Acremont, Eleonora Fornari, and Peter Bossaerts
2	Differentiating cooperative motives and affective reactions in prosocials and proselfs with fMRI	Griet Emonds, Carolyn H. Declerck, Christophe Boone, Ruth Soerinck, & Rik Achten
3	Neural Computations underlying Strategic Learning	Lusha Zhu, Kyle Mathewson, and Ming Hsu
4	Overlapping Neural Activation in Delay Discounting and Working Memory: A Meta-Analysis	Warren K. Bickel, Jeffery A. Pitcock
5	Comparing Apples and Oranges: Evidence for a Unified Subjective Value Representation in the Brain	D. Levy and P.W. Glimcher
6	Towards a Mathematical Psychiatry: Rational Modeling of Obsessive Compulsive Repetition (OCR) with Decision and Game Theory	L. Amsel and A. Pilpel
7	Noradrenaline in decision-making: pupil dilation reflects unexpected uncertainty	K. Preuschoff, B.M. ‘t Hart, W. Einhäuser
8	Neural Correlates of Anticipation Risk Reflect Risk Aversion	S. Rudorf, K. Preuschoff, C. E. Elger, and B. Weber
9	Prior and likelihood uncertainty are differentially represented in the human brain	Iris Vilares, James D Howard, Hugo L Fernandes, Jay Gottfried, and Konrad Kording
10	Motivational and Neural Differences in Reward and Risk Anticipation	John A. Clithero, R. McKell Carter, Vinod Venkatraman, David V. Smith, and Scott A. Huettel
11	Social Learning in Asset Markets: A Peek into the Herding Brain	Holger Gerhardt, David Danz, Guido Biele, Harald Uhlig, Dorothea Kübler, and Hauke R. Heekeren
12	Stochastic choice behavior predicted by the BOLD signal	Stephanie C. Lazzaro, Robb B. Rutledge, Daniel Burghart, Ifat Levy and Paul W. Glimcher
13	Different Affective Learning Systems Contribute to the Accumulation of Assets and Debt	Camelia M. Kuhnen, Brian Knutson, Gregory R. Samanez-Larkin
14	Genetic Modulation of DRD4 VNTR – Linear Relation between Functional Efficiency and Economic Uncertainty Preferences	O.A. Mullette-Gillman, E. McClaurin, K.M. Schiabor, R. Phillips, A. Robinson, E.T. Cirulli, D. Goldstein, M. Platt, J.H.P. Skene, and S.A. Huettel
15	Social Components of Motivated Deception	R.M. Carter, D.L. Bowling, and S.A. Huettel
16	An Expected Utility Maximizer Walks Into A Bar	Daniel R. Burghart, Stephanie Lazzaro, and Paul W. Glimcher
17	A Neural Model of Stochastic Behaviour Applied to Mixed Strategy Games	Ryan Webb
18	Functional coupling between hippocampus and prefrontal cortex is associated with willingness to wait for larger monetary rewards	Shan Luo, George W. Ainslie, Drusus Pollini, Lisa Giragosias, John R. Monterosso
19	Risky decision making and development: Neural recruitment from childhood to adulthood	David Paulsen, McKell Carter, Michael Platt, Scott Huettel, Elizabeth Brannon

20	Spontaneous lies in social contexts are associated to reduced motor readiness	Panasiti MS, Pavone EF, Mancini A, Merla A, Aglioti SM
21	Ventromedial prefrontal cortex interacts with posterior superior temporal cortex during valuation of social rewards	David V. Smith, John A. Clithero, Sarah E. Boltuck, Scott A. Huettel
22	Loss aversion in perceived ownership: An fMRI study of economic decision making	C. Buerger, J. Weghmann and B. Weber
23	Optimal Information Integration in a Hierarchical Decision Task	Ulrik Beierholm, Klaus Wunderlich, Peter Bossaerts and John P O'Doherty
24	Strategic and Social Decision-Making Mechanisms Support Language Processing	C. T. McMillan , R. Clark, D. Gunawardena, M. Dreyfuss, and M. Grossman
25	Double asymmetry of reciprocity: a behavioral and neurobiological study	A. Riedl, S. Okamoto-Barth, M. Strobel, A. Heinecke, H. Breman, and R. Goebel
26	How certain are you? Explicit and Implicit Measures of Decision Confidence	Joshua Sanders and Adam Kepecs
27	Value transfer in human sensory preconditioning with monetary reinforcement	G. Elliott Wimmer and Daphna Shohamy
28	The Neural Basis of Expectations in Social-Bargaining	Luke J. Chang, Alec Smith, and Alan G. Sanfey
29	Neural correlates of the influence of extrinsic rewards on intrinsic motivation	K. Albrecht, J. Abeler, B. Weber, and A. Falk
30	The Minimax Matching Hypothesis	Liam Clegg
31	The Neural Basis of Wage Valuation in Economic Search Under Uncertainty	J. Heinonen, J. Suomala, L. Palokangas and J. Numminen
32	The Dark Side of Product Attachment: Reactivity of Users and Non-Users to Addictive Product Advertising	Dante Pirouz, Cornelia (Connie) Pechmann, and Paul F. Rodriguez
33	Insensitivity to Rejection in the Ultimatum Game: Evidence from Frontotemporal Dementia	Katya Rascovsky, Corey T. McMillan, Peachie Moore, Robin Clark, Brianna Morgan and Murray Grossman

Behavioral and Neurobiological Evidence for Probabilistic Sophistication

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Probabilistic sophistication is the ability to recognize "states" behind the realization of uncertain payoffs, and to track the probabilities of these states independently of the payoffs to be received when these states occur. Examples abound of violations of probabilistic sophistication such as the Ellsberg paradox. Therefore the question arises if humans can take decisions in accordance with probabilistic sophistication and if activation related to state probability can be located in the brain. Participants decided whether to buy a gamble at a posted price during fMRI. The outcome of the gamble was determined by drawing randomly a ball from a bin. If participants choose to buy the gamble, they earned the payoff written on the ball minus the price, otherwise nothing. The bin contained balls of different colors (states) and each color was associated with a unique payoff. Participants knew the number of colors and the color-payoff association, but ignored the proportion of balls of each color. They had the opportunity to estimate it by observing several draws from the bin before taking a decision. In this sampling period, only payoff was shown and color could be inferred from it. Occasionally we changed the color-payoff association without changing the color proportion. To model probability learning during the sampling period, uniform priors were updated following Bayesian rule. A "sophisticated" agent will update probabilities based on color and will be unaffected by the color-payoff association change. An agent ignoring states will estimate payoff probabilities instead and will have to restart the estimation after the change. Analysis of choices revealed a payoff function similar to prospect theory. Value computed on color rather than payoff probabilities better predicted choices suggesting probabilistic sophistication at the behavioral level. We discovered encoding of state probabilities in left angular gyrus and medial prefrontal cortex during the sampling period. Just before decision, activation in the bilateral caudate signaled gamble utility. Activation related to entropy in bilateral anterior insula increased with utility. These results indicate that the brain is capable of tracking the probabilities of several states at the same time. Brain activation is also sensitive to the interaction between utility and entropy of state probabilities, a result unaccounted for in classical expected utility theory. The interaction is consistent with recent modeling of choice under uncertainty based on robust control theory.

Differentiating cooperative motives and affective reactions in prosocials and proselfs with fMRI

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Individual differences in social value orientation (proselfs versus prosocial) are a well-documented determinant of cooperative behavior in social dilemmas. Previous research has shown that, for proselfs, the decision to cooperate is calculative and incentive-based, while prosocials are intrinsically motivated to cooperate, which may make them particularly sensitive to breaches of trust. In this study, we use event-related fMRI to further gain insight into the neural correlates of (un)cooperative decision making of prosocials and proselfs, and additionally investigate their affective response to a non-reciprocating partner.

Method: Participants (n= 38) under the scanner engage in a series of one-shot Prisoner's Dilemma (PD) games. The first series of games, played simultaneously, reveal participants' intrinsic motivations. Later games are played sequentially (participants act as first movers) and include a feedback phase. The sequential PD games offer greater cooperative incentives and also reveal uncooperative intentions of partners. Brain contrasts are computed between the decision making phases of prosocials and proselfs in both types of games, and between their responses to a non-reciprocating partner in the sequential PD.

The following hypotheses are tested: (1) Cooperative and defect decisions of proselfs are associated with activation of brain regions involved with cognition (dorsolateral prefrontal cortex, anterior cingulated gyrus, and caudatum). (2) cooperative decisions of prosocials are associated with a 'warm glow of giving' (activating the ventral striatum and subgenual area), while defect decision are driven by fear of betrayal (amygdala activation). (3) Prosocials show a stronger emotional reaction to feedback compared to proselfs (activation of ventral striatum/subgenual area for cooperative feedback, and insula for defect feedback). (4) Prosocials show a greater emotional spill-over effect which affects their behavior in a subsequent round of the game, and (5) there is functional connectivity between activation of brain regions involved in emotions during cooperative decisions in the simultaneous PD and the affective response to a defecting partner in the sequential PD.

Conclusions: Economists have attributed sustained cooperation in populations to the behavior of strong reciprocity, referring to an individual's propensity to resist free-riding and to punish defection at a personal cost. Corroboratory evidence for the above hypotheses would substantiate the idea that prosocials possess more strong reciprocating characteristics than proselfs, and that these differences have a biological ground.

Neural Computations underlying Strategic Learning

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Objective: How an equilibrium arise in non-cooperative strategic games has been studied extensively in both the theoretical and experimental literature. The general finding is that, for nontrivial games, players gradually reach equilibrium over time through some process of adaptation, typically referred to as learning. A number of models of learning in strategic games have been proposed, in particular reinforcement and belief-based models, as well as hybrid models such as experienced weighted attraction (EWA). Here we investigate the neural basis of strategic learning, by investigating brain regions that encode learning signals used to guide behavior in a strategic setting.

Methods: We combine computational modeling of strategic learning with functional neuroimaging of a multi-strategy competitive game. Behavioral data from 30 subjects were fitted with the EWA learning model adapted into a temporal difference (TD) form, as well as the conventional reinforcement and belief based learning model. The resulting estimates were then used to construct regressors based on the respective models at the individual level. Standard *GLM* techniques were used in analyzing fMRI data.

Results: Our results show robust evidence of reinforcement and belief-based learning signals in the manner predicted by EWA learning. Somewhat surprisingly, these distinct signals are represented in both overlapping and distinct brain regions. In particular, we find that (1) many of the regions involved in encoding learning signals overlap those found in previous studies of reward learning (e.g., Lohrenz et al., 2007), such as dorsal and ventral striatum, but that (2) belief learning signals were encoded in anterior cingulated (ACC) and dorsomedial prefrontal cortices (dmPFC) in our task, but not in previous studies of learning with no strategic or social motivations.

Conclusions: Studying the neural basis of learning in games has important implications for both economics and neuroscience. In this study we build upon the well-established literature on reward learning and adding a critical strategic component. For economics, we provide novel data that may allow us to improve econometric models of learning dynamics. For neuroscience, we provide a potentially useful paradigm to study social and learning deficits in a variety of mental and neurological illnesses.

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Overlapping Neural Activation in Delay Discounting and Working Memory: A Meta-Analysis

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Objective: Recent reports suggest a strong relationship between delay discounting and working memory. For example, a study by our group found that training stimulant addicts on working memory reduced the degree of discounting more so than a yoked control group (Bickel et al, in press). Identification of the neural constituents that underlie this relationship has yet to be reported. To address this lack of knowledge, we conducted a quantitative meta-analysis of the functional neuroimaging of delay discounting and working memory to identify plausible regions of activation subserving both processes.

Methods: We identified 136 foci from five published functional neuroimaging studies of delay discounting, and 739 foci identified in 38 published studies of the imaging of working memory. Utilizing activation likelihood estimation (ALE) analysis, we distinguished brain regions consistently observed across these studies independently. We then isolated regions within the bilateral DLPFC (BA9), bilateral parietal lobule, and anterior cingulate cortex (BA32) that are present in both working memory and delay discounting studies.

Results: Our results conclude that these areas of consistently overlapping activation between the two procedures represent plausible areas of dysregulation (e.g., hypoactive executive system, hyperactive limbic system) that effect neural networks necessary for optimal decision making. These results are consistent with the competing brain regions hypothesis where the impulsive system, comprised of evolutionarily older limbic structures (anterior cingulate), and the executive system, consisting of the evolutionarily younger prefrontal cortex, work in concert with each other in the performance of optimal decision making.

Conclusion: These findings are particularly relevant for understanding some of the cognitive deficits associated with increased discount rates and corresponding deficits in working memory observed in a variety of populations.

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Comparing Apples and Oranges: Evidence for a Unified Subjective Value Representation in the Brain

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A rational chooser compares the expected utility (EU) of different options and then chooses the option with the highest EU. Comparing between apples and oranges thus logically requires a computation of the EU of each option within it's own domain and then transformation of the different EU's to a common scale for a direct comparison. Our aim was to identify both the brain areas that represent the expected subjective values (ESV – the neuronal correlate of behavioral EU) for specific reward types and brain areas that represent a unified ESV irrelevant of the reward type.

Subjects fasted for four hours and then were asked to choose between monetary and food rewards while inside the magnetic resonance imaging scanner. In the SAME lotteries, subjects had to choose between a certain small reward and a probability of either winning a larger amount of the same reward or getting nothing. In the MIXED lotteries, subjects had to choose between a sure win of a small amount of money and a probability of winning a fixed amount of food or getting nothing. At the end of the experiment, one SAME trial of each reward type and one MIXED trial were randomly selected and played for real money and real food. Subjects then had to stay in the lab for two hours without access to other food.

We computed, for each subject, the EU of all the values of money and food encountered based on their choices. We then looked for brain areas that track the ESV for money and food. We found that different subregions in the ventromedial prefrontal cortex (vmPFC) and striatum track the ESV of money and food. The posterior parietal cortex tracked only the ESV for money and the hypothalamus tracked only the ESV for food suggesting that there is, to some extent, a distinct valuation network for each reward type which we also analyzed and described with seed and Granger analyses. However, in the vmPFC and striatum there was a common area representing the ESV of both reward types, suggesting that the activity in these overlapping regions may allow comparison of the ESV across reward types.

To further test the hypothesis that a common area represents ESV independent of reward type, we used the MIXED trials data to behaviorally determine the relative pricing between money and food for each subject. This relative pricing *behaviorally* scaled the EU of money and food to a unified EU. The relative scaling of food and money ESV *activations* in the common area of the vmPFC but not in the striatum correlated significantly with the relative EU scaling for food and money measured behaviorally. This suggests that these brain areas represent ESV irrelevant of the reward type. Comparison of activity in these overlapping regions would allow one to compare apples and oranges, so to speak.

Towards a Mathematical Psychiatry: Rational Modeling of Obsessive Compulsive Repetition (OCR) with Decision and Game Theory

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Objective: Obsessive Compulsive Disorder (OCD) is an Anxiety Disorders with a lifetime prevalence of 1.9% - 2.5%, worldwide. Compulsive repetition of stereotyped behaviors is a debilitating part of OCD. Existing models from psychoanalysis, neuropsychology, and biological psychiatry have not incorporated important basic science advances in our understanding of cognitive information processing, and decision making, and have not developed satisfactory explanatory models for these apparently peculiar symptoms.

Methods: Taking Becker's ideas on rational addiction as inspiration, we apply concepts from Decision Science and Game Theory to known phenomenology of OCR to develop three rational explanatory models of compulsive repetitions: 1- Bayesian Updating, 2- Markov Chain Stochastic Updating, and 3- Regulatory Self-Signaling Game.

Results: 1- In the Bayesian model, repetitive checking events constitute a signal detection process that updates the agent's probability estimate of a potentially dangerous event. It is therefore rational to continue checking until the reduction in the expected lost is equal to the marginal cost of an additional checking event. 2- In the Markov Model, checking events have a low probability of switching the agent from a state complete uncertainty to one of certainty regarding the anticipated dangerous event, and there is no memory carried forward across checking events. Interestingly, this model has formal structure that parallels the behaviors of pathological gamblers, when they are loss-chasing. 3- The Self-Signaling Game Model includes notions of regret, and self-signaling to reduce that regret. In this game-theoretic model we assume two agents within the individual, an agent acting currently, and a second agent acting only after a catastrophic event. The costly multiple checking repetitions of the OCR agent are an inter-temporal decision aimed largely at signaling the other agent that due diligence was taken, thus avoiding punitive regret.

Conclusions: These models imply different, and empirically testable, predictions about OCD behavior. They should therefore lead to alternative research approaches to this disorder.

Noradrenaline in decision-making: pupil dilation reflects unexpected uncertainty

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Objective: Pupil dilation has been implicated as a marker for decision-processes since the 1960s; little is known, however, as to which decision variables it reflects. One plausible hypothesis states that pupil dilation is related to uncertainty, in particular to errors in judging uncertainty. As pupil diameter under constant illumination is mediated by noradrenaline (NA) released by the locus coeruleus (LC), we use pupillometry to assess the role of noradrenaline (NA) for uncertainty processing.

Methods: By using pupillometry in an auditory gambling task, we dissociate unexpected uncertainty of a monetary outcome from other decision variables, such as the probability of the outcome, expected reward or expected uncertainty.

Results: We find that pupil dilation increases with increasing levels of unexpected uncertainty. Formalizing unexpected uncertainty by risk prediction error, we find a strong correlation between the pupil dilation and this quantitative measure of unexpected uncertainty. In contrast, there is no correlation to the expected reward, the probability of the outcome or expected uncertainty, i.e., risk, per se.

Conclusions: Our data support a recent computational model, which links NA to the perception of decision-making variables, in particular to unexpected uncertainty. The coupling of NA to risk prediction error suggests that NA might play a similar role in processing uncertainty as dopamine does for reward.

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Neural Correlates of Anticipation Risk Reflect Risk Aversion

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Objective: Risk preferences are important determinants of human behavior in many domains, ranging from health attitudes to financial decisions. Recent studies highlighted the role of specific brain regions in the processing of decision risk (during or before choices; e.g. Christopoulos et al., 2009) and anticipation risk (after or without a choice; e.g. Preuschoff et al., 2008). In this study we want to investigate to what extent neural correlates of anticipation risk reflect individual risk preferences.

Methods: Using fMRI we measured neural correlates of reward and risk prediction and the corresponding prediction errors during a simple card gambling game (Preuschoff et al., 2006, 2008). Additionally, we applied a standard binary choice lottery scenario to group subjects according to their risk preferences. We also tested for functional connectivity during risk processing.

Results: We were able to replicate neural signals of reward and risk processing as reported by Preuschoff et al. (2006, 2008). In accordance with the behavioral measure of risk preferences (certainty equivalent), risk seekers showed stronger BOLD effects to reward related information while risk averters were more sensitive to risk prediction and risk prediction error. Psychophysiological Interaction (PPI) analyses contrasting high versus low risk trials revealed stronger functional connectivity of ventral striatum and anterior insula with frontal regions (IFG, DLPFC) for risk averters compared to the other groups.

Conclusions: Our findings support a two-step model of risk processing with an automatic evaluation of risk coded by ventral striatum and anterior insula that interacts with prefrontal signals of cognitive control during decisions under risk (cp. Mohr et al., 2010). Further, individual differences in risk preferences might not only be due to a lack of prefrontal control in risk seekers as suggested elsewhere (Gianotti et al., 2009, Cohen et al., 2010), but to a hypersensitive signal of anticipation risk in risk averters.

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Prior and likelihood uncertainty are differentially represented in the human brain

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Objective: Behavioral studies have shown that humans can take into account the uncertainty in both prior and likelihood in a way near to statistically optimal. However, how this uncertainty is represented in the brain is still poorly understood. Here we wanted to know which areas are involved in the representation and integration of prior and likelihood uncertainty, and whether these areas overlap.

Methods: A total of twenty-seven adult subjects participated in the behavioral portion of this study. Each subject performed a decision-making task which consisted of guessing the position of a hidden target on a screen. The position of the target was sampled from a 1-D Gaussian distribution (the prior) in which the mean was fixed and the variance was kept constant inside each block of trials, but changed between blocks. In every trial 5 dots were shown in the screen (the likelihood), whose x-position was drawn from another 1-D Gaussian distribution, in which the mean was the hidden target and the variance changed randomly between trials. The subjects were asked to guess the position of the hidden target and, after the choice was made, the real position of the target was shown. Fifteen of these subjects then performed the same task in an fMRI scanner.

Results: We found that people readily combined information from both the position of the likelihood dots as well as previous knowledge about the target distribution in a way similar to the predictions from Bayesian decision theory. Preliminary analysis showed that higher prior uncertainty was correlated with stronger activations in the insula, caudate, amygdala and putamen, while the visual cortex was more active in a more uncertain likelihood.

Conclusions: Our results indicate that the human brain makes use of different pathways to represent and integrate uncertainty about prior and likelihood, and offer a potential neural mechanism for optimal Bayesian decision making.

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Motivational and Neural Differences in Reward and Risk Anticipation

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Objective: The anticipation – not just the receipt – of rewards has been repeatedly demonstrated as a key component in the evaluative and decision-making processes in humans. Here, in a pair of brain imaging studies, we attempted to map the neural processes of reward anticipation of both certain and uncertain rewards. Given the contributions of individual variability in reward and risk sensitivity to behavior, identifying both the common and idiosyncratic neural mechanisms can lead to a better understanding of motivated behavior in various contexts.

Methods: Study 1 included 60 participants. Neural data was collected using event-related functional magnetic resonance imaging (fMRI). In order to reliably engage commonly-recruited reward-processing brain regions, we employed a modified version of the monetary incentive delay (MID) task. On each trial, subjects were first presented with one of five cues that indicated the potential of gain of cash ($1 or $5), candy (small or large amount), or nothing. After a variable anticipation interval, subjects had to press a button in response to a visual target in order to receive the reward. Study 2 included 65 participants and focused on risk management preferences; specifically how different types of risk modulate reward anticipation in a modified MID task where participants had the opportunity to improve three-outcome (ranging from -$10 to +$30) gambles. In both studies, saliva samples were collected so that genetic contributions to reward and risk processing could be identified.

Results: Consistent with the existing literature, we found that reward anticipation – regardless of reward context - robustly increased blood-oxygenation-level dependent (BOLD) signal in ventral striatum, anterior insular cortex, and medial prefrontal cortex (mPFC). This anticipatory valuation was common across reward modalities, both within and across subjects. Additionally, we found that individual measures of inferred preference (i.e., reward magnitude and calculated ratios of reaction time in each reward modality) and motivation between reward modalities tracked BOLD signal in both the striatum and mPFC.

Conclusions: These results indicate that neural valuation mechanisms can be studied independently of participant choice behavior. Further, the motivational effect of reward anticipation shares a common mapping across multiple reward modalities (candy, monetary) and for both certain and probabilistic rewards.

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Social Learning in Asset Markets: A Peek Into the Herding Brain

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Objective: Our decisions often depend on the observation of others' actions—think, e.g., of investment decisions or school choice. Theoretical models of social learning show that it can be rational to "herd": It is optimal to follow others and disregard one's own information if the informational content of others' actions dominates. However, in experiments subjects often follow preceding players to a suboptimal degree, foregoing substantial payoffs (Weizsäcker, *AER* forthc.). We aim to better understand how subjects learn from their predecessors.

Methods: We adapted a herding experiment for the fMRI environment and scanned 35 subjects at 3 T. Subjects chose repeatedly between two "stocks." In each of the 210 trials, they received two probabilistic hints as to which of the two stocks was currently profitable. In the Computer Condition, both hints were computer-generated signals, whose current accuracy in predicting the profitable stock was indicated to subjects. In the Human Condition (HC), only one hint was a computer-generated signal with known quality $p_2 \in [.6, .87]$. The other hint was the observed action of a preceding player, who had chosen a stock based on a single computer-generated signal. That signal's quality $p_1 \in [.61, .89]$, $p_1 > p_2$, was known to both players.

We estimated event-related BOLD signal changes with a GLM, including the difference of the signal qualities $p_1 - p_2$ and a measure of the quality of the obeyed signal, p_{dec}, as parametric modulators.

Results: If subjects assume first players to not always have chosen in line with their signal, they should obey their own signal if p_2 is not too far below p_1 in the case of contrary hints within HC. We find that subjects indeed follow first players the more often, the larger $p_1 - p_2$, and that responses are slower for small $p_1 - p_2$. Analyses of the fMRI data show that subjects' choices to not follow preceding players are accompanied by greater activation in the ACC, insula, striatum, precuneus, and posterior parietal cortex.

Conclusions: Having controlled for p_{dec} in the GLM, the activations we detect are not due to increased reward anticipation in the respective conditions. The observed choices, response times, and activations can be explained as follows: Subjects seem to presume that preceding players commit errors but do not know the error rate. This introduces ambiguity into the decision situation. Ambiguity aversion makes following the preceding player less attractive. The activations we find are compatible with those found by Hsu et al. (*Science* 2005) and Huettel et al. (*Neuron* 2006) for decisions under ambiguity and risk. We are, thus, the first to establish a link between social learning and ambiguity aversion.

Stochastic choice behavior predicted by the BOLD signal

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VonNeumann-Morgenstern Utility assumes that an individual has a fixed utility for each object in a choice set, an assumption that predicts fixed deterministic choices. Instead, choice is often observed to be stochastic. McFadden (1973) addressed this observation by suggesting that the utility of an object is a stochastically varying quantity. He proposed that the utility a chooser associates with a good varies randomly from trial to trial and is drawn from a fixed underlying distribution in a way analogous to the psychophysical variation of percept.

Contemporary studies using fMRI during choice suggest that activation in the medial prefrontal cortex (MPFC) encodes a utility-like signal. It is also observed, however, that the measured brain activation in the MPFC produced by a good varies from trial to trial. This trial to trial variation undoubtedly reflects measurement noise, but might it also reflect a direct measurement of random utility-like fluctuations predicted by McFadden's representational theorem?

To address that question we used fMRI to measure the blood oxygen level dependent (BOLD) signal while twelve subjects passively viewed images of fifteen different consumer goods, such as DVDs, CDs, books and posters, all having a commercial value of about $20, as well as five monetary lotteries. We sampled activation from a region of interest (ROI) in the MPFC that showed higher activation to winning $2 compared to losing $2 in a separate functional localizer task. We measured the response in the ROI to each good eleven times. After the scan, subjects made binary choices between all of the goods they had seen while inside the scanner. Subjects made each choice twice.

We have previously reported that when mean BOLD activity in the MPFC during passive viewing is higher for one good compared to another good, on average subjects later choose the good with the higher BOLD activity. Here, we ask whether the variance in the BOLD signal and the difference in magnitude of BOLD activity between two objects has an effect on the stochasticity of choice – prima facie evidence for a random utility-like signal in the MPFC.

We found that when given binary choices between goods, subjects were more likely to pick the good with lower average activation when the difference in mean activation between the two goods was smaller. This relation may indicate the existence of random utility-like signals in the value areas of the human brain and we are now investigating to what extent trial to trial variation in BOLD responses can account for stochastic choice.

Different Affective Learning Systems Contribute to the Accumulation of Assets and Debt

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Abstract

In an experimental setting that combines a financial investment task, functional brain imaging and credit report data regarding our participants' finances, we find that individuals who learn better about gains have more real-life assets while individuals who learn better about losses have less debt, and document that brain areas related to emotion processing are responsible for incorporating financial information into choice. The results are robust to the inclusion of cognitive (i.e., memory, cognitive flexibility, numeracy) and demographic (i.e., age, sex, ethnicity, education) controls. The sensitivity of the medial prefrontal cortex to expected value during gain learning and the sensitivity of the anterior insula to expected value during loss learning are predictors of individual differences in performance on the financial choice task. Moreover, within individuals, learning from gains and learning from losses are not correlated. These findings suggest that distinct systems in the emotion-related areas of the brain guide gain and loss learning and influence real-life financial outcomes.

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Genetic Modulation of DRD4 VNTR – Linear Relation between Functional Efficiency and Economic Uncertainty Preferences

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Objectives. We assessed individual economic preferences across multiple task and survey measures to identify major axes as behavioral phenotypes. Genomic assays examined how these phenotypes relate to specific genotypic differences in the functional properties of the serotonergic and dopaminergic pathways.

Methods. Over 800 individuals have participated in this study (ages 18 to 78, ~60% female and 60% Caucasian). Participants completed behavioral surveys related to decision making and performed three incentive-compatible tasks providing metrics of: uncertainty preferences (risk and ambiguity), loss aversion, and strategic/heuristic use. Saliva samples were collected to examine the effect of specific genotypes on economic preferences. Candidate variable number tandem repeats (VNTRs) were selected from the serotonergic and dopaminergic systems, including: DAT1, DRD4, 5HTTLPR, Stin2, MAOA.

Results. We identified systematic behavioral phenotypes consistent with cardinal economic formulations (e.g., Kahneman & Tversky, 1979); our cardinal two are uncertainty and loss aversion preferences. We found only very weak correlations between the loss aversion and uncertainty phenotypes across subjects (r below |.2|). Separating uncertainty preference into risk and ambiguity components, we found that, on average, subjects devalued risky gambles by 34%, and ambiguous gambles by 62%, with a highly significant within-subject correlation, r=.45. For loss aversion, our second phenotype, subjects had an average delta of -2.6 (sd: 2.1).

We examined the relationship of our VNTRs to uncertainty and loss aversion phenotypes. Using a criteria of $p < .05$ (uncorrected), we found no significant relations using standard binary categorical analyses. However, using a novel model of parametric change in the DRD4 receptor functional efficiency, we found a significant linear relation between greater DRD4 functional efficiency and both increased risk aversion, and increased ambiguity aversion. This linear model does not significantly relate the DRD4 VNTR to our loss aversion phenotype, supporting the dissociation of these cardinal economic phenotypes.

Conclusions. These results confirm that polymorphisms of the DRD4 VNTR affect individual economic uncertainty preferences, while demonstrating that DAT1, 5httlpr, Stin2, and MAOA do not. The relationships between DRD4 and risk and ambiguity aversion is found through a novel model of functional effects, from which a clear parametric effect emerged. Finally, this effect size of this relationship is much smaller than those previously reported, existing in a range appropriate for complex heritable traits.

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Social Components of Motivated Deception

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Objective: Deception constitutes a significant portion of communication. The nature of this interaction is of particular interest since it requires the deceiver to make use of information about the goals and values of the deceived. Tasks studying deception rarely provide participants with unambiguous motivation to be deceptive. Here, we use an incentive-compatible simplified poker task that we employ to identify neural components of deception that are unique to a social context.

Methods: We asked participants to play a simplified poker game during function magnetic resonance imaging (fMRI) against two opponents, an individual incentivized to catch deceit and a computer program. We used pattern classification techniques to identify portions of the brain that differentiated truthful responses from deceitful ones, contrasting patterns of activation elicited by the human and computer opponent. We also employed a combinatorial technique to identify regions that contribute unique information to the deception process.

Results: As expected, participants bluff a significant portion of the time against both opponents. Searchlight pattern classification identifies a network of regions that predict bluffing, including the medial and dorsolateral prefrontal cortices as well as a region in the temporal parietal junction. Combinatorial analysis shows that these regions do not equally contribute to bluffing in a social context.

Conclusions: The identification of deception information specific to a social context provides avenues for further segregation of the network of brain regions associated with deception.

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Title: An Expected Utility Maximizer Walks Into A Bar

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Alcohol is a commonly consumed psychoactive substance and individuals intoxicated by alcohol regularly make choices of many kinds. However, it is unclear from existing work whether individuals acutely intoxicated by alcohol consistently maximize some predefined goal (are logically consistent) or whether the consistency of their choices declines as Blood Alcohol Concentration (BAC) increases. In as much as intoxicated individuals' choices are coherent, do their preferences change with BAC?

To address these questions we engaged patrons at a bar in a set of three laboratory-like, behavioral economic experiments. The first two experiments assessed choosers' adherence to the Generalized Axiom of Revealed Preference (GARP) and the Independence Axiom (IA). GARP is an embedded assumption in any theory or model that hypothesizes choosers maximize something (e.g. *Drift Diffusion* or *Utility Theory*). The IA plays a similar role in models representing choices over uncertain outcomes as probability weighted averages (i.e. *Expected Utility*). The third experiment was designed to determine how risk attitudes change as a function of BAC.

Our GARP experiment is the design used by Harbaugh et al. (2001) except that participants choose over bundles of food served at the bar. By systematically varying the relative prices of the two foods we can test whether choosers are GARP compliant. To test adherence to IA we designed a new experiment in which subjects choose between a certain $30 and a *lottery* with three possible prizes. Manipulating the probabilities of these prizes allows us to test compliance with IA. To identify attitudes towards financial risks we employ the design used by Holt and Laury (2002, 2005); participants choose between two lotteries each with two possible prizes.

As in all economic experiments our experiments do not use deception and subject choices are incentive compatible: At the conclusion of the experiment one choice situation is selected at random to count for actual payment so subjects treat each choice as if it counts for actual payment. By exploiting natural variation in BAC, as measured with a breath alcohol meter, we are able to relate BAC to (1) violations of GARP, (2) violations of the Independence Axiom, and (3) changes in preferences toward financial risk-taking.

Preliminary evidence suggests that there is little or no relationship between BAC and compliance with both GARP and The Independence Axiom: Maximization behavior seems to be well-conserved even at BACs up to twice the legal limit for driving. In contrast, however, risk-attitudes do appear to be affected by BAC: Individuals with high BACs tend to be less averse toward taking financial risks.

A Neural Model of Stochastic Behaviour Applied to Mixed Strategy Games

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Abstract

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We develop a decision model which demonstrates the role neural processes play in generating stochastic choices in a strategic context. Using a model of spiking neurons, we demonstrate how strategy choice is the result of the interaction between the valuation of strategies, based on the history of the game, and the noise resulting from the bio-physical characteristics of neurons. Importantly, modelling the neural choice process allows the action valuation to be observable. We estimate action value using structural econometric techniques using empirical evidence from single- and dual-neuron recording sessions while monkeys compete in the matching pennies game. The model can predict both equilibrium and out-of-equilibrium strategies depending on trial-by-trial valuations. This result builds on the literature that all players have the ability to randomize over pure strategies, while providing an explanation for why we only observe mixed strategy equilibria in particular contexts.

Functional coupling between hippocampus and prefrontal cortex is associated with willingness to wait for larger monetary rewards

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"Delay discounting" can be measured with monetary intertemporal choice tasks in which participants choose between smaller sooner (SS) and larger later (LL) options. We utilized functional Magnetic Resonance Imaging (fMRI) to investigate neural correlates related to intertemporal choice. Participants (N = 31) completed an individualized intertemporal monetary choice task in which alternatives varied from those in which the SS was just sufficiently large enough to elicit 100% preference, to those in which the LL was just sufficiently large to elicit 100% preference. A logit mode was fit to each participant's overall performance and used to predict individual choices. After controlling for value of chosen alternative and reaction time, selection of LL (relative to SS) was associated with greater brain signal change in bilateral dorsolateral prefrontal cortex (dlPFC) / frontal pole, the ventromedial prefrontal cortex (vmPFC), left hippocampus / parahippocampal gyrus, and right medial temporal gyrus / superior temporal gyrus. Analysis of residuals from the logit model predicting individual choices indicated that signal was lowest in these regions when the SS choice was surprisingly myopic. A functional connectivity analysis (psychophysiological interaction) in which the hippocampus cluster was used as the seed indicated greater association with the left dlPFC, paracingulate gyrus and superior frontal gyrus when participants chose the LL (relative to SS) alternative. Results provide further evidence that intertemporal choice involves functional coupling between neural systems related to episodic imagery and cognitive control.

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Risky decision making and development: Neural recruitment from childhood to adulthood

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Objective: Previous neuroimaging studies utilizing adult participants have found specific regions of prefrontal cortex (PFC) and posterior parietal cortex to be associated with risky decision making. However, despite behavioral differences found between adults and children in choice behavior, few studies have addressed the development of risky decision making from early childhood to adulthood.

Methods: Here, we acquired functional magnetic resonance imaging (fMRI) and behavioral data in young children (6-8 years), adolescents (14-15 years), and young adults (18-35 years) as they made decisions about probabilistic and certain rewards. On *Sure Bet* trials, participants chose between two certain options that differed in value, whereas the *Gamble* trials involved a choice between two options with the same expected value but different levels of Risk. Choices resulted in tokens that could be later traded for toys or gift cards.

Results: For each participant, we calculated measures of economic risk aversion that were used as covariates of neural activation. We find increased fMRI activation in superior parietal, paracingulate, and lateral prefrontal cortices in all age groups during Gamble trials. Similar activation across age groups was also found in response to outcomes in insular cortex. In children, activation in ventral striatum and orbitofrontal cortex was correlated with risk aversion during active decision making. Group contrasts revealed both cortical and subcortical regions that were more active in adults than in children during Gamble trials, including superior parietal and insular cortices, the amygdala, and striatum. In a separate behavioral study using the same paradigm with multiple levels of Risk, overall risk aversion was found to increase from childhood to adulthood in a linear fashion. Between group differences were also found in the effect of Risk Level on risk aversion. While children demonstrated an increasing preference for risk as level of risk increased, adolescents and adults demonstrated an increasing aversion to risk.

Conclusions: The behavioral data stand in contrast to the general notion of a U-shaped function for risk aversion across development, suggesting instead that developmental profiles of risk aversion may be context or content specific. Our imaging results indicate that components of the neural systems involved with adult decision making are already present in young children, and that children's risk preference is associated with activation of these regions. These results also suggest that the development from immature to mature decision making may be characterized by the inclusion of additional decision-making circuitry. The addition of this circuitry may reflect changes in the neural architecture within and between decision-making regions as a product of biological maturation and/or experience with probabilistic decision-making contexts.

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Spontaneous lies in social contexts are associated to reduced motor readiness

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Objective: While lie is inherently spontaneous and social, most of the current experimental paradigms may not grasp the essence of this behaviour because are based on the specific instruction on when to lie or tell the truth in the absence of social interactions. To overcome this limitation we combined a novel paradigm in which subjects were free to decide when to lie to another person with event related potentials (ERPs). We hypothesized that lie may differently impact the Bereitschaftspotential (BP) an ERP component associated with preparation of volitional movements.

Methods: EEG signal was recorded from twenty subjects (SP) while they were engaged to play an on-line card game with an opponent player (OP). The OP had to choose one of two covered decks, one associated with gain and the other with loss, unaware of the outcome of his own choice. SP could saw the outcome and were supposed to report it to OP. By lying, SP could have the chance to reverse the outcome in order to win when he/she had actually lost (advantageous lie) or to lose when he had actually won (disadvantageous lie). SPs performed the game in two conditions: the Reputation-Risk (R), in which OP was informed about SP behaviour; and the No-Reputation Risk (NR) in which the OP was not informed.

Results: SP produced more advantageous lies in the NR condition. Moreover, reaction times (RT) for lie and truth responses were not different. This indicates that when subjects are not instructed as whether to lie or not but can chose freely, lies preparation do not demand any additional time with respect to truth responses.
In addition, the ERPs analysis showed that the late BP was reduced in deceptive responses.

Conclusion: Results show that freely deciding to lie in a social interaction is linked to motor preparation. The late BP is believed to reflect the selection of appropriate muscles for the action and is thought to be influenced by movement precision and complexity. The suggestion is made that, the pre-motor cortex, the activity of which is related to BP, is less ready to lie than to tell the truth.

Ventromedial prefrontal cortex interacts with posterior superior temporal cortex during valuation of social rewards

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Introduction: Many brain-imaging studies implicate the ventromedial prefrontal cortex (VMPFC) in the valuation and comparison of different goods. Yet, little is known about how other brain regions interact with VMPFC during valuation. Based on previous reports linking social reward processing and social cognition, we predicted that VMPFC would show increased functional connectivity with the posterior superior temporal cortex (pSTC), during social reward valuation.

Method: To test this prediction, we utilized two tasks. In the first task, we measured brain activation using functional magnetic resonance imaging (fMRI) while subjects (n=16) rated, on each trial, the attractiveness of unfamiliar faces. In the second task (a post-scan economic exchange task), subjects were forced to spend small sums of money to view attractive faces. On each trial, subjects were given a choice to pay more to see a more attractive face or pay less to see a less attractive face. We quantified how much each subject valued attractive faces by calculating the proportion of trials on which they exchanged money to view a relatively more attractive face.

Results: We found that responses in VMPFC and ventral striatum increased with increasing attractiveness ratings. To examine whether VMPFC interacts with social cognition regions during social reward valuation, we conducted a psychophysical interaction (PPI) analysis using posterior VMPFC (pVMPFC) as the seed region. We also introduced each subject's proportion of exchanges (average: 0.42; range: 0.1 to 0.8) as a covariate in the group-level model. Strikingly, the PPI analysis revealed that the pSTC and posterior cingulate exhibited increased connectivity with pVMPFC during social reward valuation, an effect that was dependent on the subject's willingness to sacrifice money to view faces in the exchange task.

Conclusion: These results suggest that social cognition regions interact with the pVMPFC in a subject-specific manner, with increased connectivity found in those individuals who exhibit greater valuation for social rewards.

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Loss aversion in perceived ownership: An fMRI study of economic decision making

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Objective: Economic decisions in everyday life are influenced by affective components rather than rational thought. Ownership, even being only virtual, influences our valuation of everyday goods. The discrepancy between the price accepted to sell the good and the amount one is willing to spend for an equivalent item is recognized as a measure for the endowment effect. We aimed at a consolidation of previous findings using individually chosen highly salient stimuli (DVD movies). We hypothesized the ventral striatum including nucleus accumbens to show significant BOLD-activity in response to buying opportunities, reflecting expected reward and orbitofrontal cortex activity to be correlated with subjective value. Further we expected insula activation to show interindividual differences in loss aversion.

Methods: Thirty-five subjects (age 22-58, 18 male) participated in the study. Each of them was scanned on a 1.5T Siemens Avanto while engaging in a transaction paradigm. 80 DVD Covers of previously individually chosen movies were presented in either a buying or selling condition. Subjects were asked to state their maximum price willing to pay and their minimum price to accept when selling. Functional data was analyzed using SPM8. Both conditions were contrasted and parametrically modulated by either wta (selling condition) or wtp (buying condition) and the difference between wta and wtp as a measure of the endowment effect.

Results: Behavioral data showed a substantial difference between wta and wtp, suggesting a strong endowment effect. This was accompanied by insula activation, indicating fear of losing perceivedly owned goods. As expected, we found ventral striatal activation when buying. This was modulated by wtp, with higher prices evoking increasing activation. We found orbitofrontal activity in both conditions, also correlated with absolute prices.

Conclusions: We were able to show regions known to be involved in aversive stimuli processing to be activated when selling and reward related areas when buying. These results confirm the key areas of the neural network involved in loss aversion. The strong endowment effect hints at a difference in valuation depending on the perceived status of ownership.

Optimal Information Integration in a Hierarchical Decision Task

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Objective: Most problems of realistic decision making involves choosing between options that differ along more than one dimension, however how humans solve such problems is not well understood. Similarly while it is known that prefrontal cortex is required for such adaptive behavior little is known about what computational strategy it employs. Optimal choices require integrating over all the dimensions based on their relevance, while other strategies, e.g. relying purely on the most relevant dimension, are simpler but less efficient. We wished to test what strategy humans employ in such tasks and the role the prefrontal cortex plays in this.

Methods: We used a task with two stimulus dimensions, each containing two exemplars. In each round one of those exemplars would be relevant and subjects received monetary reward based on choosing in each round this exemplar, with the relevant exemplar and dimension changing over time.
Subjects needed to establish which dimension was relevant (higher-order inference), and which exemplar within each dimension was currently rewarded (lower-order inference) and performed the task for 40 minutes while haemodynamic BOLD response was measured in a 3T MRI scanner.
We tested several competing computational strategies for how subjects might solve such a problem including a full 'Bayesian integration' of probabilistic information across all stimulus dimensions (model averaging) and a 'selecting' 2-layered decision strategy (model selection).

Results: We found evidence that subjects' behavior conforms better to a computational decision strategy in which subjects' use probability integration across relevant dimensions and exemplars, than to a two layered selection strategy.
Furthermore, neural activity in human prefrontal cortex was found to be better accounted for by the probability integration model than by the two-layer selection model. Distinct sub-regions of medial prefrontal cortex were found to correlate with the full value and the certainty within the dimension.

Conclusions: Our results indicate that human prefrontal cortex deploys a near optimal ("Bayesian" like) decision strategy in which a multi-dimension decision problem is resolved by integrating optimally across dimensions to guide choice.

Acknowledgements:
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Strategic and Social Decision-Making Mechanisms Support Language Processing

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Objective: Individuals regularly encounter pronouns with underspecified meaning in daily language (e.g., "The client chased the visitor. He laughed"). We propose that strategic and social decision-making mechanisms contribute to coordinating a pronoun's meaning with an interlocutor during conversation. We argue that there is value associated with coordinating meaning and ventral medial prefrontal cortex (vmPFC) contributes to value assessment. Additionally, theory of mind plays a critical role in adopting the perspective of an interlocutor and rostral medial prefrontal cortex (rmPFC) supports perspective-taking in theory of mind.

Methods: In two experiments we asked participants to determine a pronoun's referent in written mini-discourses (e.g. The client chased the visitor. He laughed: CLIENT or VISITOR). Participants were instructed to coordinate their choice of referent with the referent preferred by 100 previous participants, and were rewarded with monetary units each item they coordinated. Unbeknownst to participants, we differentially rewarded responses to items containing two gender-neutral nouns (as above) in 4 experimental sessions (S): we rewarded randomly in S1 and S3, a subject response in S2 (e.g., "client" above), and an object response in S4 (e.g. "visitor" above). The remaining experimental items contained a male and female noun, and participants were rewarded for selecting the correct referent. In Experiment 1 we tested behavioral-variant frontotemporal dementia (bvFTD) patients, who have a social disorder due to vmPFC and rmPFC disease, but no aphasia. In Experiment 2, we monitored BOLD fMRI in healthy adults during passive reading of these discourses.

Results: In Experiment 1, controls successfully coordinated their responses to gender-neutral nouns in a manner consistent with the reward pattern by the 4th block in S2 and S4, but bvFTD did not differentially choose the rewarded referent. bvFTD patients thus have difficulty using feedback to coordinate their choice of a pronoun's referent. In Experiment 2, we observed vmPFC activation during exposure to gender-neutral nouns in early (1-4) minus late (5-8) blocks of S2 and S4, consistent with assessment of reward. In late blocks minus early blocks of the same sessions, we observed rmPFC activation during exposure to gender-neutral nouns, consistent with the hypothesis that individuals are adopting the perspective of a hypothetical interlocutor to maintain coordination.

Conclusions: These two experiments emphasize the critical role of prefrontal cortex in coordinating meaning during a linguistic discourse. We argue that strategic and social decision-making resources support language processing.

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Double asymmetry of reciprocity: a behavioral and neurobiological study

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Objective: There seems to exist an unexplained asymmetry in reciprocity, a key regularity in human social behavior. The sensitivity to unkind behavior appears to be stronger than the sensitivity to equivalent kind behavior. Importantly, the perception of kind and unkind behavior is likely to be influenced by expectations implying that the relevant reference point is endogenously constructed via beliefs. We seek to provide clean behavioral evidence for asymmetry in reciprocity and examine its neural correlates taking expectations into account.

Methods: Eighteen right-handed subjects (11 females) were scanned using fMRI while they expressed their expected gains/losses and reciprocated with sanctioning/rewarding to other players' money offers. In two different conditions offers are made by a human player or a computer.

Results: The behavioral data clearly show asymmetric responses to perceived positive and negative offers. Strikingly, larger perceived gains are not rewarded more but larger perceived losses are more heavily punished. Moreover, this asymmetry is more salient when the offer came from a human player compared to when the computer made offers. The neuro-imaging data supports these findings and suggests more elaborate insights. Subjects' brain activity showed higher sensitivity to the negative context, in contrast to their expectation, than to the positive one. Moreover, when subjects received a very negative offer, emotion related regions in the brain such as insula, dorsal anterior cingulate cortex were activated. Contrary, when subjects faced a very positive offer, they process it as reward and activation in the ventral striatum was evoked. Social comparison of earnings also showed intriguing facets. While subjects' relative loss, when they earned less than the other player, evoked activation in the emotion regions, subjects' relative gain evoked activation in the reward regions. Interestingly, when subjects earned the same amount as the other player, they still showed a robust activation in the same reward regions, suggesting a neuronal equity preference.

Conclusions: Both behavioral and neuro-imaging results confirmed that humans evaluate perceived negative offers stronger than positive offers. We believe that our finding will help to better understand human sociality.

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How certain are you? Explicit and Implicit Measures of Decision Confidence

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Objective: Decision confidence is traditionally studied using either verbal, explicit reports or with task designs eliciting indirect, implicit confidence reports. As only implicit reports of confidence are available in animal models, a systematic comparison of implicit and explicit confidence reports will serve as a valuable link between findings in animals and humans.

Methods: We present a new confidence reporting task, in which human subjects classify auditory stimuli and report their decision confidence both implicitly and verbally in each trial. At trial onset, subjects hear simultaneous Poisson click trains in each ear, and respond by moving a joystick towards the click-train that they believe to have the faster underlying rate. The subjects then hold the joystick in the chosen direction until they are rewarded following a random delay, or until they give up and abort their attempt. 10% of trials are catch trials for which reward is omitted, forcing an eventual abort. The time spent before giving up provides an implicit measure of confidence. Following aborts, subjects rate their certainty that they have made the correct decision on a 1-5 scale using a keypad.

Results: We find that the duration a subject is willing to wait for an uncertain reward varies with difficulty, and that this relationship is opposing for correct and error trials. In other words, an easy trial performed correctly has the longest waiting time, and an incorrect easy trial the shortest, with these trends converging as difficulty increases until they are indistinguishable for trials with perfectly ambiguous evidence. Moreover, choice accuracy increases with longer waiting times. Both of these response patterns are predicted by normative models of confidence for two-choice decision tasks. We also find a strong trial-by-trial correlation between the implicit waiting time confidence measure and the explicit confidence ratings.

Conclusions: Previous studies of implicit confidence reporting tasks used “opt-out” or “uncertain option” paradigms. Our task leverages from the fact that each binary decision can be accompanied by separate implicit and explicit decision confidence reports. Our task design also sidesteps the difficulty of tailoring payoff matrices, as is necessary to discriminate between a suboptimal wagering strategy and a confidence deficit in a “post-decision wager” style task. By relating verbal and implicit confidence measures in a simple framework accessible to both rodents and humans, we provide a basis for studying the neural mechanisms underlying confidence judgments.

Acknowledgements:
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Value transfer in human sensory preconditioning with monetary reinforcement

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Objective: Reinforced stimuli often have a history of prior episodic experience. These prior experiences may influence subsequent reward-based learning and decision making. Behavioral and animal studies suggest that when two stimuli are experienced as part of an episode, later feedback-based learning about one stimulus 'spreads' to impact preferences for the other stimulus. This effect, referred to as sensory preconditioning, provides a possible mechanism by which directly learned reward associations for one item can transfer to other items, and thus affect subsequent decisions. Here, we describe a study showing that such value transfer indeed impacts monetary decisions in humans, and we examine the neural and cognitive mechanisms underlying this process. Guided by recent animal research, we hypothesized that transfer depends on multiple cognitive processes and neural systems: the dopamine-innervated striatum has been shown to support value learning, while the hippocampus supports successful episodic learning that enables transfer of value.

Methods: We used fMRI and a newly developed monetary reinforcement value transfer paradigm. In the task, neutral stimuli are first incidentally paired (with no reinforcement). Then, one stimulus from each pair is used as a predictor of monetary reinforcement (or null outcome). In a subsequent test of value transfer, participants are asked to make gamble choices among stimuli that had been directly associated with outcomes in the reward learning phase and also among familiar stimuli that had appeared in the experiment but had only been incidentally paired with other rewarded stimuli prior to reward learning.

Results: Participants successfully learned to associate stimuli with rewarding outcomes based on direct feedback. These learned values transferred to related items that were never directly associated with reward. FMRI results reveal that reward learning engaged the striatum, while transfer of value was associated with activation in the hippocampus during reward learning.

Conclusions: Together, these findings suggest that the striatum and hippocampus both support reward learning and reward-based decision making, but that each makes distinct contributions to these processes. Value transfer is one example where these cognitive processes may interact to guide future economic choices.

Acknowledgements:

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The Neural Basis of Expectations in Social-Bargaining

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Objective: Considerable effort has sought to understand how social preferences influence decision-making behavior. One prominent theory has proposed that people are motivated by an objective notion of fairness to minimize inequity in payoffs. However, growing evidence indicates that this theory cannot account for a number of recent empirical findings, and instead suggests that people appear to have expectations about the appropriate behavior for a given context. We use a formal model of this process, developed in the context of psychological game theory, to characterize the neural mechanisms underlying social-bargaining behavior.

Methods: Eighteen participants played as responder in the Ultimatum Game while undergoing fMRI. Prior to playing the game we elicited players' beliefs about the offers they expected to encounter. Using these initial beliefs, we directly compared our expectation model with an alternative distributional preference model to determine which could provide the best account of the behavioral data. To characterize the neural basis of expectations, we examined both deviations from expectations using a linear contrast, and also the interaction with initial expectations.

Results: Our results indicate that after controlling for the amount of money offered, expectations were able to predict responder's decisions. In addition, our model of expectations was a better fit to the behavioral data then the distributional preference model. Imaging analysis revealed that deviations from initial expectations track with activity in the left insula, anterior cingulate, and supplementary motor area. Additionally, the relationship between expectation violation and insula activity appeared to be moderated by participant's initial expectations.

Conclusions: These results support our hypothesis that individual expectations play an important role in social interactions, and that violations of these expectations produce responses in the brain consistent with negative affect. This study demonstrates how formal models of cognition can be utilized to better characterize the neural processes underlying social behavior.

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Neural correlates of the influence of extrinsic rewards on intrinsic motivation

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Objective: Psychological and economic theories assume that extrinsic rewards influence intrinsic motivation. It is mostly suggested that monetary rewards crowd out intrinsic motivation whereas verbal reinforcement should affect intrinsic motivation positively. A range of behavioral studies support the central tenets of these theories. In our study, we want to investigate what influence these two kinds of extrinsic rewards have on brain activation while subjects perform a cognitive task. We expect a higher decrease of activation in the brain's reward circuitry after monetary rewards were given compared to when no extrinsic motivation was provided before. We hypothesize the opposite for verbal reinforcement.

Methods: Forty-five subjects participate in our functional magnetic resonance imaging (fMRI) experiment, which consists of three parts. In part 1, subjects solve a series of picture puzzles without receiving any reward for solving a puzzle correctly. In part 2, one third of the subjects is doing the task without any reward (treatment 1), one third receives a monetary reward for every correctly solved puzzle (treatment 2), and one third receives verbal reinforcement for every correctly solved puzzle (treatment 3). In part 3, all subjects do another series of puzzles without receiving an extrinsic reward.

Results: Our main interest lies in differences in the brain activation between part 1 and 3 within treatments, and in differences within part 3 between treatments. Results will be presented and discussed.

The Minimax Matching Hypothesis

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Objective: Numerous experiments have found probability matching (PM) behavior in individual decision making under uncertainty, but this strategy is clearly sub-optimal under the traditional interpretation. I show that PM is the optimal strategy in certain zero-sum games with asymmetric information, and I present evidence from previous studies suggesting that the human brain evolved to play such games.

Methods and Results: I present two new theoretical results, showing PM to be a minimax strategy in certain repeated zero-sum games, and also the result of a learning process which converges to mixed strategies in a broader class of games. I outline the neural mechanisms required to support such a strategy. These include an endogenous reward system that responds preferentially to unexpected positive stimuli, suggesting an evolutionary role for the pleasure generated by the dopamine activity of a reward-prediction error (RPE) learning system.

Conclusions: These results suggest that many cases of individual decision making, both experimental and empirical, can be modeled profitably as zero-sum games against unseen rational opponents. Humans may make sub-optimal decisions from time to time because in a competitive environment, it pays to be unpredictable.

Acknowledgements:
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The Neural Basis of Wage Valuation in Economic Search Under Uncertainty

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Objective: Although that the Prospect Theory (PT) value function has been used to explain a variety of behavior in fields ranging from economics to many other disciplines, choice behavior in economic search has been explained without the consideration of PT. In order to study the role of a subjective Reference Point (RP) in economic search, we constructed a fMRI experiment to represent the elements present in a subjective choice situation.

Methods: It was designed a ROA (Reject Or Accept) experiment for fMRI studies. The subjects (n=18) evaluated a set of salary offers by rejecting or accepting the offer. Before the fMRI scan, the subjects answered a question on their personal salary goals after graduation (=subjective RP). The content of the offers varied depending on the participants' subjective RP. However, the range of offers was the same. The fMRI scans were arranged at the AMI Center of the Aalto University by GE 3 Tesla MRI scanner. During the fMRI scan, 100 sets of salary offers were presented, one at a time, for the participants to judge between *accept* and *reject*. In order to keep choice situation uncertain the content of offers were based on two different uniform distributions.

Results: We analyzed the fMRI data to identify brain regions whose activation correlated with the size of the wage offer using the PT valuation function. We performed a whole-brain analysis to identify areas that correlated with the amount of wages offers. There were 7 types of offers varied from 30% below to 30 % above of RP.
We found that the activity in the lateral frontal orbital cortex (OFC), the ventral paracingulate gyrus (PCG), the posterior/anterior cingulate cortex/ precuneus (ACC) and the lateral parietal cortex (angular gyrus) were correlated with the amount of wage offers.

Conclusions: The study shows that the brain responds to the amount of the wage offers and the intensities of these brain areas correspond to the characterics of the value function in the PT. As previous studies have shown, the OFC represents the valence. In addition, the other brain areas, PCG and ACC, extensively overlap the default network, which has been consistently linked to self-referential stimuli. Thus, the study shows that PT can explain human's behavior, when single subjects reference point is known. To the best of our knowledge, this is the first time when the choice behavior during economic search has been explained by PT.

ABSTRACT

The Dark Side of Product Attachment: Reactivity of Users and Non-Users to Addictive Product Advertising

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Advertising is a ubiquitous and pervasive environmental cue. The average consumer, for example, is exposed on average to three thousand ads per day (Schwartz 2004). Under normal circumstances, consumers choose which advertising messages to attend to both consciously and non-consciously (Bargh 2002; Grunert 1996). However for consumers, environmental stimuli may elicit a unique type of response affecting decision making and driving behavior (Bernheim and Rangel 2004). The aim of this research is to explore how environmental stimuli affect addictive product users and non-users and includes two studies, one using functional magnetic resonance imaging (fMRI) and the other using laboratory experiments with ad-exposed non-users and users. Understanding if and how addictive product ads affect consumers would provide an important contribution to consumer behavior theoretical models in addition to the improvement of regulatory measures to minimize consumer harm.

Brain imaging data for study 1 showed that non-users who viewed addictive product ads had higher activation in brain regions associated with craving and cognitive resource depletion. Users, on the other hand, had a more complicated reaction. While they exhibited higher activation in some of the regions associated with craving and cognitive resource depletion, they also displayed a significant deactivation pattern in specific brain regions associated with craving and cognitive resource depletion, distinct from those regions that showed an activation pattern. These results indicated that while non-users may be unwittingly vulnerable to the effects of addictive product ads, users employed coping strategies that mitigated their craving and depletion responses.

Study 2 looked at how craving and cognitive resource depletion in non-users and users were affected by exposure to addictive (vs. non-addictive) product ads. It also examined whether ad-induced craving in non-users and users elicited cognitive resource depletion for products not directly related to the addictive product ads. The study recruited over 1600 young adult non-users and users to view ads embedded in a mock magazine format and to complete a questionnaire. Non-users reported higher craving levels and demonstrated higher cognitive resource depletion effects when exposed to addictive (vs. non-addictive) product ads. Conversely users exposed to addictive product ads (vs. non-addictive) reported lower craving and no significant effects for cognitive resource depletion.

Insensitivity to Rejection in the Ultimatum Game: Evidence from Frontotemporal Dementia

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Background: The behavioral variant of frontotemporal dementia (bvFTD) is characterized by a progressive impairment in social interaction due to focal prefrontal degeneration. These patients frequently engage in risky behaviors and seem to be unaware of the consequences of their actions.

Objective*:* To study social-decision making in bvFTD by use of Dictator (DG) and Ultimatum (UG) games.

Methods*:* Seventeen bvFTD patients and 16 healthy controls engaged in one-shot Dictator and Ultimatum games. In the DG, the subject divided a hypothetical endowment of $100 between himself and the experimenter. In the UG, the subject was told that the experimenter could reject the offer, resulting in both players receiving nothing.

Results: Normal controls significantly increased their offers when threatened with the possibility of rejection (DG offers <UG offers). However, patients with bvFTD offered similar amounts in both DG and UG conditions. Voxel-based morphometric analyses of high resolution MRI revealed significant atrophy in prefrontal, limbic and basal ganglia regions in bvFTD relative to controls. Regression analyses related offers in the UG to grey matter atrophy in the insula and rostral medial prefrontal cortex (rmPFC).

Conclusions: Patients with bvFTD have significant impairments in social decision-making related to their fronto-limbic disease. They may not be able to infer whether the recipient will accept their offer as fair (due to deficits in perspective-taking), and/or may be relatively insensitive to negative consequences such as possible rejection. Atrophy in rmPFC may impair perspective-taking about the likely actions of others, while atrophy in the insula may alter visceral markers of risk and inequity. BvFTD appears to be an excellent model for the study of social decision-making.

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Keywords: frontotemporal dementia, bvFTD, decision-making, neuroeconomics, social cognition

Saturday, October 16, 2010

Abstracts for Session V

Learning and Choice I

Chair: Eric Johnson

3:45 – 4:05 pm	Greg Samanez-Larkin	Learning and decision making in the aging brain	G.R. Samanez-Larkin and B. Knutson
4:10 – 4:30 pm	Jamie Roitman	Nucleus accumbens responses differentiate action selection following Go and NoGo cues	J.D. Roitman, A.L. Loriaux, and M.F. Roitman
4:35 – 4:55 pm	Michael Platt	Neuronal implementation of optimal foraging decisions	Michael L. Platt and Benjamin Y. Hayden

Learning and Decision Making in the Aging Brain.

G.R. Samanez-Larkin,1,2 and B. Knutson,1.
1 Psychology, Stanford University; 2 Psychological Sciences, Vanderbilt University.

Objective: Although a growing body of research has linked age-related deficits in attention, memory, and cognitive control to changes in medial temporal and lateral prefrontal cortical function, remarkably little research has investigated the influence of aging on valuation and associated mesolimbic function in the striatum and medial prefrontal cortex. The experiments presented here focus on age-related changes in value-based probabilistic learning.

Methods: The experiments investigated age differences in value-based learning and decision making. In these tasks, healthy adult participants ranging in age from 18–85 attempted to maximize monetary earnings by choosing between cues probabilistically associated with rewards. In the first study, a group of adults completed the tasks while undergoing fMRI, and in the second study younger and older adults played modified versions of the same tasks in the laboratory (with additional supports that attempted to improve decision making).

Results: Overall, neuroimaging results suggest that age-related changes in mesolimbic function (e.g., changes in variability and the representation of prediction errors) are associated with changes in learning and decision making. However, the follow-up behavioral experiments also reveal that age-related impairments are reduced or eliminated under supportive task conditions (designed to target the brain systems identified using neuroimaging).

Conclusions: As the proportion of older adults continues to grow rapidly here in the U.S. and across the globe, aging adults may be required to make more independent health-related and financial decisions. Thus, it is increasingly imperative to better understand the impact of age-related psychological changes on decision making. Overall, the results suggest that age-related changes in mesolimbic function are associated with changes in learning and decision making. However, the evidence that these age differences can be eliminated provides potential targets for the future development of environmental supports to improve decision making.

Nucleus accumbens responses differentiate action selection following Go and NoGo cues

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Objective: Impulsive behavior results when one is unable to inhibit action in response to a cue associated with positive outcomes. Neurons in the nucleus accumbens (NAc) have been shown to respond to both reward-predictive cues and goal-directed approach behaviors- events which are typically confounded. We dissociated whether NAc activity represented cue reward-prediction or action selection by recording the activity of individual neurons while rats performed a symmetric Go/NoGo task. In this task, both Go and NoGo cues predicted reward, but required either approach or inhibition to receive the reward.

Methods: Eleven rats were trained to perform the symmetric Go/NoGo task. On 80% of trials, one cue (Go) was presented simultaneously with the availability of a lever. When pressed within 4s, rats received a sucrose pellet reward. Failure to press resulted in a 40s time out. On the remaining 20% of trials, a different cue (NoGo) was presented simultaneously with the availability of the same lever. If rats withheld pressing for 4.5s, they received the same reward, while pressing in error resulted in a 40s time out. While rats performed this task, we recorded the activity of multiple individual neurons in the NAc (n = 196).

Results: Rats performed at high levels of accuracy for both Go (*M* = 88.6%, *SE* = 1.8) and NoGo trials (*M* = 76.8%, *SE* = 6.4). Neurons in the NAc responded with transient increases and decreases to both cue types. Moreover, the same neurons differentially responded to the two cues with the response to each cue dependent on the subsequent behavioral response. Neurons with increasing activity showed larger increases when rats subsequently withheld presses for both correct NoGo trials and error Go trials compared with trials in which the lever was pressed. In decreasing neurons, we found greater reductions associated with lever press for both correct Go trials and error NoGo trials compared with trials in which pressing was inhibited.

Conclusions: These findings suggest that the neural activity in the NAc to reward-predictive cues is linked directly to the action selected, with approach associated with larger decreases in activity and behavioral inhibition associated with larger increases. These findings are compatible with the idea reductions in NAc activity permit the execution of goal-directed actions.

Acknowledgements:
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Neuronal Implementation of Optimal Foraging Decisions

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Evolutionary Anthropology, Duke University

Abstract

Objective: Despite the universal importance of obtaining nutrients for survival and reproduction, we know almost nothing about the neural processes that control foraging decisions. When an animal forages in a patchy environment, the marginal value theorem (MVT) specifies the optimal patch-leaving time based on cumulative reward, handling time, and travel time to the next patch. A wealth of evidence supports the idea that animals as diverse as bees, wasps, spiders, fish, birds, seals, and human subsistence foragers obey the MVT. Even modern humans 'foraging' for information on the internet do so by abandoning websites when the information intake rate falls below the average for all websites—as predicted by the MVT. The ubiquity of foraging behavior consistent with the MVT suggests a simple and powerful mechanism mediates optimal foraging decisions of this type. We hypothesized that the brain calculates a decision variable that incorporates all the factors that influence patch leaving decisions and compares the value of this statistic to a threshold specifying optimal patch abandonment. We further hypothesized that this variable is represented by neurons in anterior cingulate cortex (ACC), a brain region associated with monitoring rewards in the environment and transforming this information into high-level action plans, especially as they relate to changing strategies

Methods: We studied the choices made by monkeys performing a laboratory implementation of a patch foraging task while the firing rates of single ACC neurons were recorded using standard extracellular electrophysiological techniques.

Results: Monkeys made nearly optimal decisions in this task. Patch residence times increased with increasing travel time and decreased with increasing handling time, as predicted by the MVT. ACC neurons responded phasically to rewards and these responses increased with both increasing patch residence time and decreasing reward. When these responses reached a threshold, monkeys chose to abandon the current patch for a new one. When travel times rose, monkeys chose to remain in patches longer, the gain of neural responses fell, and firing rate thresholds for patch leaving increased.

Conclusions: These observations suggest that patch-leaving decisions are governed by at least two distinct neural control processes—changes in response gain and threshold—and indicate that dACC neurons encode an integrated decision variable signaling the instantaneous need to change behavioral strategy. Previous studies have confirmed the generality of thresholding as a fundamental mechanism governing both perceptual judgments and action planning. Our results suggest that the brain implements fundamentally similar mechanisms to control complex decisions common in natural behavior.

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Sunday, October 17, 2010

Abstracts for Session VI

Learning and Choice II

Chair: Scott Huettel

9:10 – 9:30 am	Matthew Wanat	The stress-related peptide, corticotropin-releasing factor, acts in the ventral tegmental area to attenuate phasic dopamine release to rewards but not their predictors	Matthew J. Wanat, Antonello Bonci, and Paul E. M. Phillips
9:35 – 9:55 am	Jian Li	Differential roles of human striatum and amygdala in associative learning	Jian Li, Daniela Schiller, Geoffrey Schoenbaum, Elizabeth A. Phelps, and Nathaniel D. Daw
10:00 – 10:20 am	Elise Payzan-LeNestour	Risk, estimation uncertainty, and unexpected uncertainty: Brain mechanisms mediating Bayesian learning under three kinds of uncertainty	E Payzan-LeNestour S Dunne, P Bossaerts, and J O'Doherty

The stress-related peptide, corticotropin-releasing factor, acts in the ventral tegmental area to attenuate phasic dopamine release to rewards but not their predictors.

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Chronic stress and related pathology (e.g., depression) have profound effects on motivated behavior, producing lethargy, anergia and decreased responsiveness to rewards. Paradoxically though, stress increases tonic dopamine levels, and the stress-related peptide, corticotropin-releasing factor (CRF), increases the baseline firing rate and potentiates glutamate receptor current in dopamine neurons, effects seemingly more consistent with a pro-motivational stimulus. However, in spite of this knowledge on changes in baseline dopamine activity and release, little is known about the influence of stress on phasic dopamine transmission that discretely encodes temporally precise information about rewards and their predictors. We utilized fast-scan cyclic voltammetry to examine phasic dopamine release to rewards and reward-predictive cues in the nucleus accumbens of rats performing an operant task under a progressive ratio (PR) reinforcement schedule for natural reinforcers and tested the effects of CRF thereon. In separate sessions, we assessed behavior and dopamine release in rats under different motivational states (food-deprived or free-fed), for different reward magnitudes, and in following administration of CRF. The cumulative number of rewards earned scaled with the reward size in a given PR session. Interestingly, we found that motivational state and reward size robustly scaled reward-evoked dopamine release, while cue-evoked dopamine release was less sensitive to these manipulations. CRF injected into the ventral tegmental area lowered the breakpoint in PR sessions and attenuated reward-evoked dopamine release but did not affect cue-evoked dopamine release. These results suggest that CRF modulates motivated behavior by selectively altering information transmitted in afferents to the ventral tegmental area representing the delivery of rewards.

Differential roles of human striatum and amygdala in associative learning

Jian Li,[1] Daniela Schiller,[1,2] Geoffrey Schoenbaum,[3,4] Elizabeth A. Phelps[1,2] & Nathaniel D. Daw[1,2]

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Effective learning hinges on an animal's capability to successfully process both cues and reinforcers. Traditional reinforcement learning theory focuses on the reinforcement side, claiming that learning is driven by the deviation between expected and experienced rewards, called prediction error (PE, as in the Rescorla-Wagner and Temporal Difference rules). PE learning signals have been linked to activity in the striatum and dopaminergic midbrain in both appetitive and aversive tasks.

Another brain structure implicated in associative learning is the amygdala. Unlike in the striatum, PE does not seem to characterize learning-related signals in the amygdala. An alternative learning model, the Pearce-Hall rule, emphasizes the impact of cue-specific attention, called "associability," in gating associative learning, and has recently been linked to amygdala activity in an instrumental reward task in rodents (Roesch et al., 2010).

Here, in a Pavlovian fear reversal-learning task in humans, we explored whether these different learning signals would characterize the unique contributions of the striatum and amygdala. We demonstrate that BOLD activity in the human striatum and amygdala track the dynamics of different components of leaning signals. Specifically, activity in the striatum appears to encode prediction error while amygdala activity instead correlates significantly only with associability. Both signals were characterized by a hybrid of Rescorla-Wagner and Pearce-Hall rules in which cue-specific associabilities gate error-driven reinforcement learning. The difference between the two areas' correlations is demonstrated by a significant interaction ($p<.02$) between factors of region (striatum or amygdala) and signal (PE or associability) in a repeated-measures ANOVA. These results suggest that the striatum and amygdala have computationally unique, but collaborative roles in associative learning.

Risk, Estimation Uncertainty, and Unexpected Uncertainty: Brain Mechanisms Mediating Bayesian Learning under Three Kinds of Uncertainty

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Objective: Learning under partial reinforcement can involve three levels of uncertainty: *Risk* (even if you know the outcome probabilities, the next outcome is uncertain), *Estimation uncertainty* (you don't know the outcome contingencies, but can learn them), and *Unexpected Uncertainty* (the outcome contingencies jump stochastically over time). There is emerging evidence that human behavior reacts differentially to the three levels, as it should if the decision maker is Bayesian (model-based reinforcement learner). We explored the neural underpinnings of such Bayesian learning. We conjectured separate neural signals for the three levels of uncertainty.

Methods: 17 subjects were scanned using fMRI while they performed a partial reinforcement task involving six slot machines. On each trial, either one or two slot machines were presented. Subjects indicated their chosen machine. The outcome returned by the chosen machine was then displayed: either -1 EUR or +1 EUR or 0 EUR. The outcome probabilities of the machines jumped stochastically during the course of the task. We used a Bayesian learning model to measure how much Risk, Estimation Uncertainty, and Unexpected Uncertainty the subject perceived at each trial. A general linear model of the fMRI data was then estimated with model-generated learning rates and (orthogonalized) uncertainty signals as parametric regressors inferred from the choice data.

Results: We found significant activation correlating with uncertainty signals after purposely accounting for emotion-, attention-, and control-related activation modulated by the learning rate (evident in, e.g., amygdala, inferior frontal gyrus and cerebellum). Activation in anterior insula increased with the risk of the chosen option, and simultaneously, activation in anterior cingulate cortex, parietal cortex, and medial frontal gyrus correlated with estimation uncertainty. After display of the outcome, activation in anterior cingulate cortex, posterior cingulate cortex and insula correlated with unexpected uncertainty. These activations overlap with those reported in studies where each of the three levels of uncertainty was investigated separately (at times without control of the other levels).

Conclusions: The results suggest that the human brain represents three quintessentially Bayesian kinds of uncertainty signals separately, even after accounting for activation correlating with changes in the learning rate.

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Sunday, October 17, 2010

Abstracts for Session VII

Valuation I

Chair: Hilke Plassmann

11:00 – 11:20 am	Z Kurth-Nelson	Effects of contingency representation on decision making	Z. Kurth-Nelson and A.D. Redish
11:25 – 11:45 am	Klaus Wunderlich	Markowitz in the brain: learning about correlated rewards	Klaus Wunderlich, Mkael Symmonds, Peter Bossaerts, and Ray Dolan
11:50 am – 12:10 pm	Camillo Padoa-Schioppa	Dissociating economic choice from action planning: Contributions of orbital and lateral prefrontal cortices	Camillo Padoa-Schioppa

Effects of contingency representation on decision making

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Experiments show that animals faced with a decision can represent explicit expectations of future outcomes. If outcome expectancy is used to evaluate decisions, then changing an agent's beliefs about contingencies, without changing valuation or learning processes, can qualitatively alter decisions. Here, we perform computational simulations of decision making under varying contingency beliefs. The contingency beliefs of the agent are represented as *state spaces*, where discrete situations are classified as states, and the states are linked by transitions describing how one situation leads to another (either spontaneously or through the action of the agent). We characterize how different state spaces lead to different patterns of decision making. In particular, a simple change of state space can cause a switch from addictive to non-addictive behavior.

Sometimes it is possible to pre-commit to a particular choice before the choice becomes available. We simulate pre-commitment using a state from which two choices are available: to enter a state where either a small immediate or large delayed reward can be selected, or to enter a state where only a large delayed reward is available. In the simulations, the agent simultaneously prefers an impulsive choice when it is available and prefers to commit to avoid the impulsive choice.

It is also possible for altered contingency beliefs to change decisions even when the actual contingencies of the world do not change. In decision making in repeated trials of a choice between small immediate and large delayed rewards, if the simulated agent uses a state space in which the terminal state of one trial has a transition to the initial state of the next trial, it exhibits less impulsive behavior than if consecutive trials are not linked by transitions.

We also simulate a state space in which a single choice of drinking leads to subsequent drinks being unavoidable. Switching from a state space in which choice continues to be available to this new state space results in a switch from preferring the first drink to preferring to avoid the first drink, due to the diminishing benefits of more heavily discounted future drinks.

These results raise the possibility that, because decision making depends on state space representations, addiction (and other disorders of choice) may be treatable by training general cognitive skills, influencing contingency beliefs, or by explicitly altering contingencies. Conversely, drugs may exert addictiveness partly by pharmacologically disrupting the construction of healthy state spaces.

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Markowitz in the brain: learning about correlated rewards

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Objective: Previous studies have shown that the brain is able to track the mean and variance of rewards and update those signals via prediction errors. We tested the hypothesis that, in a situation where knowledge about the co-variation of rewards can improve performance, subjects also learn about the correlation between outcomes and use this information to guide choices. We searched for neural representations of relevant decision variables in the brain to identify the neural mechanisms by which subjects solve such portfolio optimization problems.

Methods: We scanned 18 subjects with fMRI while they performed a portfolio mixing task. On each trial, subjects were presented with fluctuating returns from two energy sources, solar and wind power, and asked to create an energy portfolio by allocating weights in a way that minimizes the total portfolio fluctuation over time. This required learning the distribution of returns for each resource as well as their correlation. Importantly, the assets' correlation changed probabilistically over time, entailing subjects to continuously update their current estimate. We used a computational model based on reinforcement-learning to estimate subjects' trial by trial predictions of value and risk variables and respective prediction errors, and correlated those model-predicted time series against the fMRI data.

Results: Behavioral results show that subjects were able to construct risk optimal portfolios by learning information about variance and covariance of the assets. We found evidence for a neural representation of the correlation strength in bilateral insular cortex. Furthermore, various components of covariance prediction error signals, which might be used to update those estimates, were found in distinct regions of parietal and medial temporal cortex.

Conclusions: Our results demonstrate that subjects use information about the covariance between outcomes in order to optimize task performance. The neural representations of subjects' current covariance estimates indicate that the brain can track information about the relationship between rewards directly in covariance space and use this data to optimize choices.

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Dissociating economic choice from action planning: contributions of orbital and lateral prefrontal cortices

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According to the good-based model, economic choices take place within the space of goods, abstract from the sensorimotor contingencies of choice. Following a decision, the choice outcome guides a suitable action plan. We previously showed that neurons in the orbitofrontal cortex encode values independently of the actions associated with the ava5lable offers – values are thus *computed* in goods space. However, we did not rule out that values may be*compared* through action selection. Most importantly, the neural processes through which the choice outcome is transformed into an action plan ("good-to-action transformation") remain poorly understood. To shed light on these issues, we used a behavioral paradigm that dissociates economic choice from action planning, and we recorded the activity of individual neurons in several areas of the primate frontal lobe. Preliminary results from one animal suggests (1) that choices can indeed be made independent of action planning and (2) that early stages of the good-to-action transformation involve the lateral prefrontal cortex.

Sunday, October 17, 2010

Abstracts for Session VIII

Valuation II

Chair: Peter Bossaerts

1:20 – 1:40 pm	Hauke Heekeren	How the brain integrates costs and benefits during decision making	Hauke Heekeren
1:45 – 2:05 pm	Cary Frydman	The neurobiological basis of realization utility during stock-market transactions	Cary Frydman, Colin Camerer, Nick Barberis, Antonio Rangel

How the brain integrates costs and benefits during decision making

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When we make decisions, the benefits of a decision option often need to be weighed against accompanying costs. Cost-benefit integration, thus, is an important aspect of decision-making. However, value-based decision making is typically investigated in the context of decision uncertainty, so that little is known about the neural mechanisms underlying the integration of costs and benefits as such. Cost-benefit based decision making involves the binary decision to either accept or reject a choice option based on two competing attributes - the option's expected rewards and losses. Such binary accept vs. reject decisions bear a strong resemblance to two-alternative choices in perceptual decision making. I will report results of a recent fMRI study, in which we tested the hypothesis that that cost-benefit decisions involve an analogous decision mechanism, i.e., the computation of a decision variable that is based on the difference of neural reward and loss anticipation signals.

The Neurobiological Basis of Realization Utility During Stock-Market Transactions

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Abstract:

Economists have shown that investors tend to exhibit a disposition effect: they tend to sell assets that have gone up in value, while holding assets whose value has declined. A potential explanation for this effect is the presence of a realization utility signal, in which individuals derive a hedonic experience at the time of selling an asset that is proportional to the current price of the stock minus its cost basis. This type of utility function is capable of explaining observed trading patterns, but is controversial in the social sciences because it leads to sub-optimal trading behavior.

In order to test the validity of this explanation we carried out a human fMRI experiment in which subjects traded in an experimental stock market. Importantly, our design allowed us to dissociate neural responses between two types of events: responses to information about changes in the price of a stock, and value computations during trading decisions. We hypothesized that subjects would encode value signals for the stocks at the time of selling in the ventromedial prefrontal cortex consistent with the presence of a realization utility effect.

Our behavioral results show that 65% of subjects demonstrate a significant disposition effect, a costly mistake in our experiment. Neurally, we found that activity in the vmPFC and ventral striatum correlated positively with the price of the stocks and negatively correlated with their costs, both at the time of decision.

This provides strong evidence for the hypothesis that the disposition effect is driven, at least in part, by the presence of a realization utility component in subjects' hedonics.

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