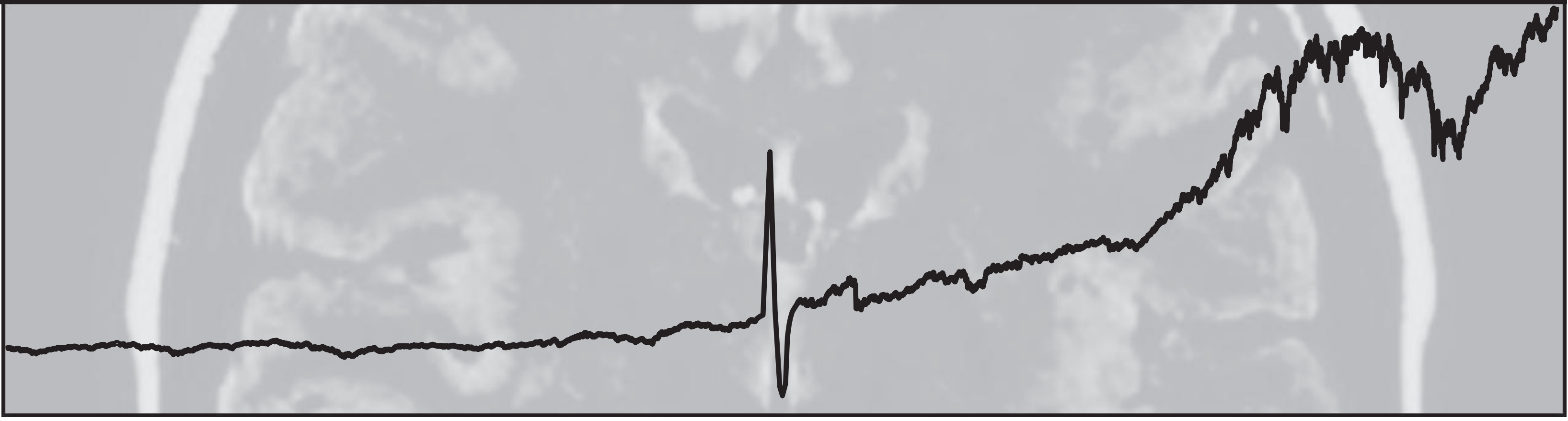
Meeting Program



7TH ANNUAL MEETING

Evanston, IL

SEPTEMBER 25-27, 2009

SOCIETY FOR
NEUROECONOMICS

Schedule of Events for Neuroeconomics 2009, 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, September 25, 2009

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*	Economics for Neuroscientists *Location: Grand Parlor AB*
9:00 – 10:30 am	Neural circuit models of decision making Xiao-Jing Wang, Yale University	Decision making under uncertainty: Theory and evidence Peter Bossaerts, California Institute of Technology
10:30 – 11:00 am	*Coffee Break*	
11:00 am – 12:30 pm	Neurogenetics Pate Skene, Duke University	Economic theory of consumer behavior Antonio Rangel, California Institute of Technology

12:45 – 1:45 pm *Lunch*

1:50 – 2:00 pm	Michael Platt President, Society for Neuroeconomics	Welcome & Opening Remarks

Social Decision Making

Chair: Scott Huettel

2:00 – 2:20 pm	Luke Chang	Deconstructing the neural correlates of emotion in social decision-making with Psychological Game Theory	L.J. Chang, A. Smith, M. Dufwenberg, & A.G. Sanfey
2:25 – 2:45 pm	Jaroslaw Grygolec	A neuroeconomic study of social observability and personal pesponsibility in decision making: An fMRI experiment	J. Grygolec, G. Coricelli, A. Rustichini
2:50 – 3:10 pm	Frans van Winden	Neural evidence of social yies: On the role of empathy and sympathy in sharing	Frans van Winden, Johannes Fahrenfort, Richard Ridderinkhof, & Benjamin Pelloux
3:15 – 3:45 pm		*Break*	

Social Reward

Chair: Laurie Santos

3:34 – 4:05 pm	Bill Harbaugh	Is it better to give or to receive?	William T. Harbaugh, Ulrich Mayr, Jim Andreoni, Benjamin Bushong
4:10 – 4:30 pm	Elizabeth Tricomi	Value computations in the brain's reward circuitry reflect equality considerations	E. Tricomi, A. Rangel, C.F. Camerer, & J.P. O'Doherty
4:35 – 4:55 pm	Karli Watson	Social reward encoding in primate orbitofrontal cortex	Karli Watson & Michael Platt
5:00 – 7:00 pm		Poster Session I *& Refreshments, Cash Bar*	*Location: Heritage Ballroom & 2nd Floor Foyer*

7:15 – 9:15 pm *All-Attendee Banquet*

Evening Event

Please join us after dinner at *Tommy Nevins Pub* for cocktails, pool, and darts. Show Maggie your nametag to get a wristband for 25% off your bill starting at 9pm!

Tommy Nevins Pub is located three blocks from the conference, at 1454 Sherman Ave, Evanston IL 60201

Saturday, September 26, 2009

9:00 – 10:20 am	*Continental Breakfast*	*Location: Grand parlor CD*
9:00 – 10:20 am	*Women in Neuroeconomics Networking Breakfast*	*Location: 9th Floor Foyer*

Value Systems

Chair: Hilke Plassmann

10:25 – 10:45 am	Cendri Hutcherson	Parallel reinforcement learning signals in the hippocampus and striatum guide acquisition of stimulus-outcome and stimulus-reward associations	Cendri A. Hutcherson & Antonio Rangel
10:50 – 11:10 am	Mathias Pessiglione	Hemispheric dissociation of the human brain valuation system	Mathias Pessiglione, Stefano Palminteri, Liane Schmidt & Gilles Lafargue
11:15 – 11:35 am	Jan Peters	Complementary valuation systems in the human brain	J. Peters & C. Büchel.

11:40 am – 1:00 pm	*Buffet Lunch*	*Location: Grand parlor CD*
11:40 am – 1:00 pm	*Lunchtime Discussion with the President of the Society (Confirmed student attendees only please)*	*Location: Northshore Room*
1:00 – 3:00 pm	Poster Session II	*Location: Heritage Ballroom & 2nd Floor Foyer*

Emotion and Decision Making

Chair: Liz Phelps

3:05 – 3:25 pm	Nichole Lighthall	Stress modulates sex differences in BOLD response and behavior during decision making	N.R. Lighthall, M. Sakaki, S. Vasunilashorn, S. Somayajula, L. Nga, & M. Mather
3:30 – 3:50 pm	Lasana Harris	Disgust reactions to trustees and dictators modulate punishment decisions in economic games	Lasana Harris, Christine Hosey, Stefanie Molicki, Ernst Fehr, Elizabeth Phelps

Afternoon off; dinner on your own

Special Evening Event

Join us for a bonfire at the beach!

Where: Lakefill fire pit (see map handed out at registration)

When: 8:00 – 11:00 pm, Saturday September 26, 2009

What: Bonfire, open bar*, snacks, and fresh air

**Open bar includes choice of two beers, house wines, sodas, and bottled water. Other alcohol can be purchased with cash.*

This event is co-sponsored by:

Duke University's
Center for Neuroeconomic Studies

Sunday, September 27, 2009

8:30 – 9:30 am		*Continental Breakfast*	
9:30 – 9:40 am	Michael Platt President, Society for Neuroeconomics	Announcements	

Temporal Discounting

Chair: Paul Glimcher

9:40 – 10:00 am	Bernd Figner	The neural basis of intertemporal choice: Single vs. dual valuation accounts and the role of self-control	B. Figner, D. Knoch, E. J. Johnson, A. R. Krosch, S. H. Lisanby, E. Fehr, & E. U. Weber
10:05 – 10:25 am	William Hedgcock	Neurological correlates of diminished self-control	William Hedgcock, Kathleen Vohs, & Akshay Rao
10:30 – 10:50 am	Shan Luo	Neural and behavioral correlates of value for lone anticipated rewards exhibit steeper delay discounting than do preferences	Shan Luo, George W. Ainslie, Lisa Giragosian, John R. Monterosso
10:55 – 11:25 am		*Break*	

Computational Neuroeconomics

Chair: Peter Bossaerts

11:25 – 11:45 am	Woo-Young Ahn	Neural correlates of subjective outcome evaluation: Model-based fMRI with hierarchical Bayesian parameter estimation	W-Y. Ahn, A. Krawitz, W. Kim, R. Fukunaga, J.R. Busemeyer & J.W. Brown
11:50 am – 12:10 pm	Kerstin Preuschoff	Risk-minimization through Q-learning of the learning rate	K.Preuschoff & P.Bossaerts
12:15 – 12:35 pm	Debajyoti Ray	A Bayesian model of behaviour in sequential economic games with applications to computational psychiatry	D. Ray, P. R. Montague, & P. Dayan
12:40 – 1:40 pm		*Buffet Lunch*	

Uncertainty

Chair: Elke Weber

1:45 – 2:05 pm	Rhanor Gillette	Value, risk, reward and decision in neuronal circuitry of a simple model animal	Rhanor Gillette, Vanessa Nobo, Keiko Hirayama & Jeffrey Brown
2:10 – 2:30 pm	Rick Jenison	Uncertainty coding by single neurons in the human amygdala	Rick L. Jenison, Hiroyuki Oya, & Matthew A. Howard III
2:35 – 2:55 pm	Colin Camerer	The boggled mind: Choice overload and neural correlates of choice set size	Elena Reutskaja, Axel Lindner, Rosemarie Nagel, Richard A. Andersen, & Colin F. Camerer

Poster Session I: Friday 5:00 – 7:00 pm

#	Title	Authors
1	Evaluating the "prominent deck B phenomenon" of the Iowa Gambling Task under the two payment procedures of gain and loss in an extended series of 300 trials	C. H. Lin, Y.C. Chiu, and J.T. Huang
2	Comparing the uncertainty effects of two payment procedures under an extended series of 300 trials in the Soochow Gambling Task	Y.C. Chiu, J.T. Huang, T. J. Song, C. C. Wang, D. R. Yeh, and C. H. Lin
3	Examining the validity in the clinical version of Iowa Gambling Task	C.H. Lin, C.J. Song Y.Y. Chen, and Y.C. Chiu
4	Reexamining the Aging Effect in the Iowa Gambling Task	C.H. Lin R.J. Hung, Y.C. Chiu, S.S. Yen, C.C. Wang, and T.J. Song
5	Retesting the somatic feedback induced by caffeine in the Iowa Gambling Task	C.H. Lin, S.Y. Lin, S.S. Yen, and, Y.C. Chiu
6	Decision-making in the Iowa and Soochow gambling tasks by Patients on Methadone Therapy	C.H. Lin, Y.C. Chiu, C.C. Wang, D.R. Yeh, T.J. Song, and C.C. Tseng
7	An fMRI Study of Reward Processing in Methamphetamine Users	Benjamin C. Gunter, Gregory Z. Tau, Félix L. García, Marc E. Shuldiner, Shan Yu, Alessandra Calvo-Friedman, Zhishun Wang, Diana Martinez, and Bradley S. Peterson
8	Preliminary results from an fMRI investigation of self-control over cigarette smoking	Louise D. Cosand, Xochitl Cordova, Jodi Ginsburg, Shan Luo, George Ainslie, John R. Monterosso
9	Financial and Psychological Risk Attitudes Associated with Two Single Nucleotide Polymorphisms in the Nicotine Receptor (CHRNA4) Gene	Brian E. Roe, Michael R. Tilley, Howard H. Gu, David Q. Beversdorf, Wolfgang Sadee & Timothy C. Haab
10	Preference is more than just liking: an fMRI study of food preference	Brian G. Essex, and David H. Zald.
11	The Sweet Side of Sugar: The Effect of Raised Insulin Levels on Price Fairness Judgments	Tim Eberhardt, T. M. Fojcik, Mirja Huber, M. Linzmajer, and P. Kenning
12	Comparing The Expected Subjective Values of Primary and Monetary Rewards	D. Levy and P.W. Glimcher
13	The role of anterior cingulate cortex in self-control	Benjamin Y. Hayden, Sarah R. Heilbronner, and Michael L. Platt
14	The influence of extrinsic rewards on intrinsic motivation	K. Albrecht, J. Abeler, A. Fal1 , and B. Weber
15	Individual Differences in Anticipation of Distinct Reward Categories	John A. Clithero, Crystal C. Reeck, R. McKell Carter, David V. Smith, Vinod Venkatraman, Justin R. Meyer, J. H. Pate Skene, Michael L. Platt and Scott A. Huettel
16	The economics of physical effort	Gregory L. Dam , Camelia M. Kuhnen & Konrad P. Körding
17	The Neural Basis of Other-Regarding Preferences	Daniel R. Burghart and Paul W. Glimcher
18	Testing Other-Regarding Preferences in Sociopaths	Ming Hsu, Eric Set, Alexander Slade, Edelyn Verona
19	Reward Sensitivity for Self and Others	R. McKell Carter, Elizabeth T. Cirulli, John A. Clithero, Justin Meyer, O'Dhaniel A. Mullette-Gillman, David V. Smith, Adrienne Taren, Vinod Venkatraman, David B. Goldstein, Michael L. Platt, J.H. Pate Skeene, and Scott A. Huettel
20	The vmPFC is involved in making decisions for self and other	Vanessa Janowski, Colin Camerer, Antonio Rangel
21	Using neurometrics of value to solve the public goods free-rider problem	Ian Krajbich, Colin Camerer, John Ledyard, Antonio Rangel
22	Reward and associative learning in the posterior cingulate cortex	S. R. Heilbronner, and M. L. Platt
23	On the Pertinence of Reinforcement Learning for Risk Control	A.D.Nursimulu, K.Preuschoff P.Bossaerts
24	Neural Mechanisms of Social Learning and Cognitive Imitation	C. J. Burke, P. N. Tobler, M. Baddeley & W. Schultz
25	A psychometric-neurometric comparison of subjective value in vmPFC during decision under risk	Shih-Wei Wu, Shinsuke Shimojo, John O'Doherty, Paul Glimcher, Antonio Rangel
26	Sleep related changes in attribute recall and choice	U.R. Karmarkar, R. M. C. Spencer, and B. Shiv
27	A Salesforce-Specific Theory of Mind Scale: Tests of Its Validity by Multitrait-Multimethod Matrix, Confirmatory Factor Analysis, Structural Equation Models, and Functional MRI	Carolyn Yoon, Roeland C. Dietvorst, Willem J. M. I. Verbeke, Richard P. Bagozzi, Marion Smits, and Aad van der Lugt

28	So close and so much invested: Goal proximity and sunk effort escalate frustration	Rongjun Yu, Dean Mobbs, Ben Seymour, James Rowe, Andrew J Calder
29	Medial prefrontal cortex mediates the competitive component of social decision making	Nadège Bault, Mateus Joffily, Aldo Rustichini, and Giorgio Coricelli
30	The Influence of Communication on Non-Interpersonal Trust: The Case of eBay	M. Hubert, R. Riedl, P. Kenning
31	Shared neural substrates for social and non-social reward processing	Alice Lin, Ralph Adolphs, and Antonio Rangel
32	Propensity for selfish behavior in the dictator game is affected by frame-order parsing	A. E. Pereira
33	Social Decision-Making in the Elderly	David R. Roalf, Mahria R. Lebow, Suzanne H. Mitchell, William T. Harbaugh & Jeri S. Janowsky
34	Mechanisms of Social and Non-social Framing Effects	David V. Smith, Vinod Venkatraman, R. McKell Carter, Justin R. Meyer, John A. Clithero, J. H. Pate Skene, Michael L. Platt1, Scott A. Huettel
35	Trust games – are effort and money equivalent?	I. Vilares, G. Dam and K. Kording
36	Neural reactions to inequity	Bernd Weber, Klaus Fliessbach,Jan-Christoph Schoene-Bake, Peter Trautner, Marieke Schnabel, Courtney Philips, Christian Elger, Armin Falk

Poster Session II: Saturday 1:00 – 3:00 pm

#	Title	Authors
1	Net Emotional Response Strength and fMRI: Preliminary Results	M. Hubert *, M. Hubert , F. Hansen , A. Bechara , and P. Kenning
2	I love Shopping? Neural Antecedents of Compulsive Buying	M. Hubert, M. Hubert, T. Eberhardt, and P. Kenning
3	Expectation of Wage Offer Inherits the Properties of Prospect Theory Value Function: Behavioral Evidence from fMRI Study	J. Suomala, V. Leppihalme, J. Heinonen, and J. Numminen
4	The decimal effect: nucleus accumbens activity correlates with within-subject increases in delay discounting rates	Kacey A. Ballard, Sébastien Houde, Shayla Silver-Balbus, Samuel M. McClure
5	Probability discounting of brain stimulation reward	Y.-A. Breton, K. Conover & P. Shizgal
6	Don't Stop Thinking About Tomorrow: Neural Measures of Future Self-Continuity Predict Temporal Discounting	Hal Ersner-Hershfield, G. Elliott Wimmer, Brian Knutson
7	The value of work: Role of dopamine in effort discounting	Suzanne H. Mitchell
8	Executive Control of Intertemporal Choice: Effects of Cognitive Load on Impulsive Decision-Making	Sarah J. Getz, Damon Tomlin, Leigh E. Nystrom, Jonathan D. Cohen, Andrew R. A. Conway
9	Cuing of post-reward delays substantially reduces impulsivity in macaques in an inter-temporal choice task	J. Pearson, B.Y. Hayden, and M.L. Platt.
10	Single frontal neurons encode probabilistic reward prediction errors	S.W. Kennerley and J.D. Wallis
11	Role of orbitofrontal cortex in confidence judgments in rats	G.M. Costa, A. Lak, Z.F. Mainen, A. Kepecs
12	Value-based gain control: a model of context-dependent choice	Kenway Louie and Paul Glimcher
13	Dissociable Neural Signals for Valuation and Salience at the Time of Decision Making	Ab Litt, Hilke Plassmann, Baba Shiv and Antonio Rangel
14	A Bayesian account of the role of attention in value-based decision-making.	D. Ray and A. Rangel
15	The Relative Role of Visual Saliency and Value in Rapid Saccadic Choice	Milica Milosavljevic, Vidhya Navalpakkam, Christof Koch, & Antonio Rangel
16	Cognitive modulation of goal values at the time of decision making	Cendri Hutcherson, Hilke Plassmann, James Gross, Antonio Rangel
17	Retrospective Evaluations in Capuchin Monkeys: The evolution of end-point sensitivity	Venkat R. Lakshminarayanan, Webb C. Phillips, and Laurie R. Santos
18	Personal, generic and automatic: three core features of the brain valuation system	Maël Lebreton, Soledad Jorge, Vincent Michel, Bertrand Thirion and Mathias Pessiglione
19	Valuation in a Sequential Choice Task Utilizes Dorsomedial Prefrontal Cortex	C. Luk, and J.D. Wallis
20	Supplementary eye field reflects both value and direction of the saccadic choice in a gambling task	Veit Stuphorn, Na Young So
21	Dynamical Bayesian computations of decision values in vmPFC	Shih-Wei Wu, Shinsuke Shimojo, John O'Doherty, Antonio Rangel
22	Asymmetric BOLD responses to positive and negative outcomes	Robb B. Rutledge, Paul W. Glimcher
23	Seeking rewards and avoiding punishments over the adult life span	G.R. Samanez-Larkin, L.L. Carstensen, and B. Knutson
24	The Contingency of Gain and Loss Influences Decision Making in a Modified IGT	Nai-Shing Yen, Chang-Hao Kao, I-Chen Chou, Hsuan-Yu Lin, Hui-Kuan Chung, Kuan-Hua Chen
25	The Neuroeconomics of Money	Donald Wargo
26	Why hire a broker? Neuroeconomic factors and financial decision making	John M.R. Chalmers, William T. Harbaugh, Ulrich Mayr, Benjamin Bushong, Eric Duquette
27	Using a computational phenotype to investigate the genetic basis of decision-making under risk	Cary Frydman, Colin Camerer, Peter Bossaerts, Antonio Rangel
28	Individual and genetic differences in risk preference and loss aversion	O.A. Mullette-Gillman, K.M. Schiabor, E.T. Cirulli A.G. Robinson, J.R. Meyer, D.B. Goldstein, M.L. Platt, J.H.P. Skene, and S.A. Huettel
29	Which neural reactions do negative payoffs cause in risky decision making?	Marcus Heldmann, Ralf Morgenstern, Thomas Münte, Bahram Mohammadi, Bodo Vogt

30	Is brain activity observable that leads to an evaluation of a probability of 0.5 that is different from 0.5 in binary lottery choices?	Marcus Heldmann, Ralf Morgenstern, Thomas Münte, and Bodo Vogt
31	Measuring Strategic Uncertainty and Risk in Coordination-, Entry-Games, and Lotteries: an fMRI study	Andrea Brovelli, Frank Heinemann, Rosemarie Nagel and Giorgio Coricelli
32	Coding of risk and expected value by distinct neurons in the orbitofrontal cortex	M. O'Neill and W. Schultz.
33	Neurometric Predictors of Risky Decision Making in Children	David Paulsen, McKell Carter, Scott Huettel, Michael Platt, Elizabeth Brannon
34	Will Gamble for Food: Risk Sensitivity with Pigeons in a Token-Reinforcement Paradigm	Carla H. Lagorio and Timothy D. Hackenberg
35	Learning to avoid financial losses: a critical role for the insula.	Stefano Palminteri, Virginie Czernecki, Carine Karachi, Laurent Capelle and Mathias Pessiglione

Friday, September 25, 2009

Workshop: Neuroscience for Behavioral Scientists

Session 1, 9:00 - 10:30 am

Neural Circuit Models of Decision Making

Xiao-Jing Wang

Yale University

~ Coffee Break~

Session 2, 10:30 - 11:00 am

Neurogenetics

Pate Skene

Duke University

Workshop: Economics for Neuroscientists

Session 1, 9:00 - 10:30 am

Decision making under uncertainty: Theory and evidence

Peter Bossaerts

California Institute of Technology

This nano-course will cover the main concepts of formal choice theory, emphasizing decisions under uncertainty and over time. Topics: Utility theory, expected utility theory, risk aversion, prospect theory, moment-based choice theory, the Allais paradox, the Ellsberg paradox, intertemporal substitution, discounting, probabilistic sophistication, learning.

~ Coffee Break~

Session 2, 10:30 - 11:00 am

Price theory for neuroeconomists

Antonio Rangel

California Institute of Technology

This workshop will provide a brief introduction to economic models of consumer decision making, including the weak and strong axioms of revealed preferences, equivalences between choice and preference data, utility representation theorems, income and substitution effects, the Slutsky equation, direct versus indirect utility functions, Marshalian and Walrasian demand, consumer surplus and other measures of consumer well-being.

Friday, September 25, 2009

Abstracts for Session 1

Social Decision Making

Chair: Scott Huettel

2:00 – 2:20 pm	Luke Chang	Deconstructing the neural correlates of emotion in social decision-making with Psychological Game Theory	L.J. Chang, A. Smith, M. Dufwenberg, & A.G. Sanfey
2:25 – 2:45 pm	Jaroslaw Grygolec	A neuroeconomic study of social observability and personal pesponsibility in decision making: An fMRI experiment	J. Grygolec, G. Coricelli, A. Rustichini
2:50 – 3:10 pm	Frans van Winden	Neural evidence of social yies: On the role of empathy and sympathy in sharing	Frans van Winden, Johannes Fahrenfort, Richard Ridderinkhof, & Benjamin Pelloux

Deconstructing the neural correlates of emotion in social decision-making with Psychological Game Theory

L.J. Chang[1], A. Smith[2], M. Dufwenberg[2], & A.G. Sanfey[1*]

[1]Department of Psychology, University of Arizona; [2]Department of Economics, University of Arizona

[*]Correspondence to: asanfey@u.arizona.edu

Objective: For many years there has been considerable interest across several disciplines in understanding the psychological and neural processes underlying social interactions. Neuroeconomics has the unique ability to combine the strengths of psychology, economics, and neuroscience to overcome methodological barriers to studying these complex high-level processes, yet relatively few studies have attempted to do so to date. One potential reason is that classical economic theory has not been particularly successful in describing actual individual behavior in these social interactions. Thus, we used tools from Psychological Game Theory to incorporate psychological principles of emotion into individual utility functions in order to model 2nd player behavior in two different games (Ultimatum and Trust Games). We then used predictions from the formal models to highlight neural systems underlying these emotions.

Methods: We used two Psychological Game Theoretic models to gain a greater understanding of the neural processes underlying emotion in social decision-making behavior. Specifically we examined guilt-aversion in the context of a Trust Game (N=17) and anger in the context of an Ultimatum Game (N=18) while participants underwent fMRI. Our imaging analyses incorporated different aspects of the formal models into separate levels of the mixed effects general linear model. This allowed us to parametrically examine these constructs on both a trial-to-trial basis as well as across individuals.

Results: Overall, our models were successful in predicting participant's behavior and were able to highlight neural systems underlying our hypothesized psychological constructs of emotion. Both guilt-aversion and anger were associated with the anterior insula, emphasizing its importance in negative emotions and also in enforcing social norm compliance.

Conclusions: These results demonstrate how the strengths of psychology, economics, and neuroscience can be integrated to study high-level social processes. More specifically, we demonstrate that the predictive power of economic models can be dramatically improved by incorporating psychological principles, and that the use of formal models can allow more specific inquiry into the neural computations underlying high level cognitive and affective processes.

A Neuroeconomic Study of Social Observability and Personal Responsibility in Decision Making: An fMRI Experiment

J. Grygolec[1*], G. Coricelli[12], A. Rustichini[3].

[1]Ceter for Mind/Brain Sciences, Univ. of Trento; [2]Institut des Sciences Cognitives in Lyon,
[3]Dept.of Economics, Univ. of Minnesota and Univ. of Cambridge.

[*]Correspondence at: jgrygolec@gmail.com

Objective: We investigated whether and how nature of observability (private vs. social), degree of responsibility (external vs. personal) and their interactions influence the evaluation of outcomes in a simple decision problem.

Methods: We conducted 20 sessions of the experiment with 60 subjects total. In each session an adult male was scanned in fMRI while two subjects were at computers outside the scanner, all making choices between two binary lotteries, 75 trials total. We examined two factors: observability (private vs. social), degree of responsibility (external vs. personal) influencing the importance of counterfactual comparison of obtained and unobtained outcomes. In the end of each trial we collected subjective mood ratings, which we used as proxy for experiences utility in behavioral analysis. We analyzed brain data with two types of models: a GLM with tercile predictors and a GLM with continuous predictors of counterfactual comparison, defined either as a difference between obtained and unobtained outcomes or as an unobtained outcome. In all models we controlled for the obtained outcome with appropriate predictors.

Results: The analysis of behavioral data shows that the very same positive outcome is more desirable if it is socially observable rather than privately, and in case of personal rather than external responsibility (or chance). There is also the positive interaction between social observability and personal responsibility. The results of brain data analysis conform to behavioral findings. If outcomes are socially observable rather than just privately we find increased activity in ventral striatum, a part of neural reward system, and Brodmann Areas 6 and 8, both implicated in the process of attributing mental states to others. In situations ensuing personal rather than external responsibility we find increased activation in two parts of neural reward system: orbitofrontal cortex and ventral striatum.

Conclusions: Both behavioral and neural findings imply that social observability and personal responsibility increase the importance of counterfactual comparisons. This suggests that envy/pride effects may be responsible for human competition rather than the institutions on which economics focuses.

Acknowledgements:
This study was funded by the NSF grant award no. 0452477.

Neural Evidence of Social Ties: On the Role of Empathy and Sympathy in Sharing

Frans van Winden [1†], Johannes Fahrenfort [1], Richard Ridderinkhof [1] and Benjamin Pelloux [2]

[1] University of Amsterdam, [2] University of Amsterdam and University of Lyon

[†] Correspondance at: f.a.a.m.vanwinden@uva.nl

Objective: Recent theoretical and behavioral studies (van Dijk and van Winden 1997, van Dijk et al. 2002, Sonnemans et al. 2006) have provided some support for the existence of a social ties mechanism inducing sympathy (or antipathy) between people interacting in an economic environment. In this study, we use fMRI to see whether a neural basis for this mechanism can be found.

Methods: We had 29 pairs of subjects participating in this experiment. Each subject n the scanner was matched with an anonymous other participant who was in another room. Participants' brain activity was measured using fMRI while they were involved in a novel Neural Distributional Preferences Test, with real monetary incentives, both before and after a spell of economic interaction. Using these neural data, we are able to search for empathic neural responses triggered by a situation in which, as opposed to previous neural studies of empathy (e.g. Singer et al. 2006), outcomes benefiting the other are involved.

Results: We find that empathic neural responses in several brain regions related to reward are conditioned on the mere presence of the economic interaction (that is, independent of its quality). More particularly, we find that more empathic players showed greater activity in the striatum (a region associated with value and reward) when the other subject is receiving money during the post-interaction test. Moreover, we observe an impact of the cooperativeness of the other player on the activation of the posterior Superior Temporal Sulcus (pSTS) and the Posterior Cingulate Cortex (PCC), which may be interpreted as a representation of a social tie between the two players. Further supporting this interpretation is the finding that subsequent behavior in the economic interaction is predicted by the difference in activation of the pSTS and the PCC between the pre- and the post-tests. In contrast, the empathy related activity in the striatum is not predictive in this respect.

Conclusions: The results of this study suggest that empathic neural responses may only emerge if preceded by an interaction. Moreover, cooperative interaction fosters social ties (sympathy). Brain activity further suggests that the pSTS and the PCC play an important role in the formation of social ties and consequently in social economic decision making.

Acknowledgment: This study was funded by NWO.

Friday, September 25, 2009
Abstracts for Session 2

Social Reward

3:34 – 4:05 pm	Bill Harbaugh	Is it better to give or to receive?	William T. Harbaugh, Ulrich Mayr, Jim Andreoni, Benjamin Bushong
4:10 – 4:30 pm	Elizabeth Tricomi	Value computations in the brain's reward circuitry reflect equality considerations	E. Tricomi, A. Rangel, C.F. Camerer, & J.P. O'Doherty
4:35 – 4:55 pm	Karli Watson	Social reward encoding in primate orbitofrontal cortex	Karli Watson & Michael Platt

Is it better to give or to receive?

William T. Harbaugh(1), Ulrich Mayr(1), Jim Andreoni(2), Benjamin Bushong(3)

(1) University of Oregon, (2) University of California - San Diego, (3) California Institute of Technology Student

Correspondence: wtharbaugh@gmail.com

Objective: While every charitable act involves a recipient as well as a giver, almost all experimental work on altruism focuses on the giver. Our research here is an attempt to complete the circle by providing a neural explanation for what goes on inside the minds of people who are receiving charity.

Methods: We recruited undergraduates and pre-screened a sample who were moderately high need and merit, but not very high need and merit, based on GPA and Pell Grant eligibility. We did fMRI scanning while they received fellowships ($50 to $150) which were designated moderate need, high need, moderate merit and high merit. The prescreening ensured all subjects received aid that they were and were not technically qualified for. We used both mandatory conditions where subjects were simply told that they had received a certain amount from a certain fund, and voluntary conditions in which they could reject aid, leaving money in that fund for other qualified students.

Results: Subjects' behavioral responses are very sensitive to the variables of interest: students are more likely to accept aid when they are qualified with respect to GPA or need, they prefer merit aid to need aid, and they are less likely to accept aid when it reduces what is available for others. There's a surprising willingness to turn down help – three of our subjects accepted less than 50% of the offers, and only three accepted all offers. Within subjects in the voluntary trials, we find that the BOLD response in evaluative areas is higher in those voluntary trials where people are qualified for the aid than when they are not, but that there is no difference between the need and merit based aid. For an across subjects analysis we divided the subjects into two groups, one that accepted charity most of the time and one that tended to turn down aid when it cost others a lot or when they were not qualified for it. The neural data from the mandatory conditions is strikingly different across these groups. Those who generally accept aid show increases in evaluative areas in the mandatory conditions where they get aid that they aren't qualified for, or aid which costs others a lot. Those who tend to turn down aid do not show activation increases in these same areas.

Conclusions: These results suggest that being told you will get aid and having to choose whether to accept aid are quite different in their neural effects. Turning down aid and leaving the money for others is, at least among some people, associated with activations similar to what is found during charitable giving. Receiving aid when that aid costs others is only rewarding for some people. Many people will turn it down, and their activation differences when given mandatory aid correlate with that behavior.

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Value computations in the brain's reward circuitry reflect equality considerations

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Objective: A large body of behavioral evidence shows that people dislike unequal outcomes, a pattern called "inequity aversion," presumably because feelings of guilt or envy can decrease the subjective appeal of a monetary reward if others are getting a larger or smaller reward. The striatum and ventromedial prefrontal cortex (vmPFC) have been shown to be involved in processing the value of monetary and primary rewards, and exhibit some sensitivity to social components of reward, but it is unknown if activity in these regions are influenced by social preferences for equality as inequity-aversion models predict.

Methods: We conducted an fMRI experiment to examine how inequity aversion effects are instantiated in the brain. Forty participants performed the experiment in pairs. The two members of each pair were paid asymmetrically at the start of the experiment. One player (in the "rich" condition) received a $50 bonus to the base pay. The other player (in the "poor" condition) received no bonus. We then scanned participants as they each performed an identical task in which they rated how appealing they found further potential monetary transfers from the experimenter to themselves and the other subjects.

Results: We determined each individual's social preferences for inequality by regressing their ratings against the amount transferred to self and to the other person for each subject. The inequity manipulation differentially affected the value ratings of the two groups: the ratings of the poor group were positively correlated with payments to themselves and negatively correlated with payments to the rich player, whereas the ratings of the rich group were positively correlated with both payments to themselves and to the poor player. Activation of the ventral striatum and vmPFC was also influenced by the inequity manipulation. The striatum and vmPFC responded more strongly as the monetary value of transfers to themselves increased than as the value of transfers to the other player increased, whereas the rich group showed the opposite pattern.

Conclusions: Our results suggest that the brain's basic reward valuation mechanisms incorporate social preferences for fairness, which indicates that these areas might play a central role in incorporating fairness considerations into social decision making.

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Social reward encoding in primate orbitofrontal cortex

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Economic exchange requires the conversion of value across multiple reward modalities. When deciding whether to purchase a celebrity photo magazine, for example, one must calculate the subjective value of the visual reward (the magazine) and convert that value into equivalent monetary units. How this conversion is computed in the brain is still unknown. We sought insight into this question by recording from single neurons in the orbitofrontal cortex (OFC) while macaque monkeys performed a choice task that pitted fluid rewards against the opportunity to view pictures of conspecifics. We previously showed that male monkeys differentially value images of female sexual signals, dominant faces, and subordinate faces. Here we show that a large fraction of neurons in the OFC respond differentially to different types of social images (e.g., female hindquarters versus faces), and, moreover, that this firing rate varies monotonically with the subjective value of each image type inferred from behavioral preferences. As a population, firing rates of OFC neurons showed both tonic modulations and phasic responses to both fluid rewards and pictures. Moreover, firing rate encoded image value at multiple time epochs when complete information about the rewards associated with each were known. Surprisingly, which choice the monkeys made had no impact on firing rate. This finding is consistent with the idea that OFC is involved in assigning value to various outcomes but lies upstream of the conversion of that information to motor output embodying choice. Finally, we found that the representation of image value and juice value varied across subregions of orbitofrontal cortex, with stronger modulation of firing in Brodmann's area 13 than in either 12 and 14.

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Poster Session I: Friday 5:00 – 7:00 pm

#	Title	Authors
1	Evaluating the "prominent deck B phenomenon" of the Iowa Gambling Task under the two payment procedures of gain and loss in an extended series of 300 trials	C. H. Lin, Y.C. Chiu, and J.T. Huang
2	Comparing the uncertainty effects of two payment procedures under an extended series of 300 trials in the Soochow Gambling Task	Y.C. Chiu, J.T. Huang, T. J. Song, C. C. Wang, D. R. Yeh, and C. H. Lin
3	Examining the validity in the clinical version of Iowa Gambling Task	C.H. Lin, C.J. Song Y.Y. Chen, and Y.C. Chiu
4	Reexamining the Aging Effect in the Iowa Gambling Task	C.H. Lin R.J. Hung, Y.C. Chiu, S.S. Yen, C.C. Wang, and T.J. Song
5	Retesting the somatic feedback induced by caffeine in the Iowa Gambling Task	C.H. Lin, S.Y. Lin, S.S. Yen, and, Y.C. Chiu
6	Decision-making in the Iowa and Soochow gambling tasks by Patients on Methadone Therapy	C.H. Lin, Y.C. Chiu, C.C. Wang, D.R. Yeh, T.J. Song, and C.C. Tseng
7	An fMRI Study of Reward Processing in Methamphetamine Users	Benjamin C. Gunter, Gregory Z. Tau, Félix L. García, Marc E. Shuldiner, Shan Yu, Alessandra Calvo-Friedman, Zhishun Wang, Diana Martinez, and Bradley S. Peterson
8	Preliminary results from an fMRI investigation of self-control over cigarette smoking	Louise D. Cosand, Xochitl Cordova, Jodi Ginsburg, Shan Luo, George Ainslie, John R. Monterosso
9	Financial and Psychological Risk Attitudes Associated with Two Single Nucleotide Polymorphisms in the Nicotine Receptor (CHRNA4) Gene	Brian E. Roe, Michael R. Tilley, Howard H. Gu, David Q. Beversdorf, Wolfgang Sadee & Timothy C. Haab
10	Preference is more than just liking: an fMRI study of food preference	Brian G. Essex, and David H. Zald.
11	The Sweet Side of Sugar: The Effect of Raised Insulin Levels on Price Fairness Judgments	Tim Eberhardt, T. M. Fojcik, Mirja Huber, M. Linzmajer, and P. Kenning
12	Comparing The Expected Subjective Values of Primary and Monetary Rewards	D. Levy and P.W. Glimcher
13	The role of anterior cingulate cortex in self-control	Benjamin Y. Hayden, Sarah R. Heilbronner, and Michael L. Platt
14	The influence of extrinsic rewards on intrinsic motivation	K. Albrecht, J. Abeler, A. Fal1 , and B. Weber
15	Individual Differences in Anticipation of Distinct Reward Categories	John A. Clithero, Crystal C. Reeck, R. McKell Carter, David V. Smith, Vinod Venkatraman, Justin R. Meyer, J. H. Pate Skene, Michael L. Platt and Scott A. Huettel
16	The economics of physical effort	Gregory L. Dam , Camelia M. Kuhnen & Konrad P. Körding
17	The Neural Basis of Other-Regarding Preferences	Daniel R. Burghart and Paul W. Glimcher
18	Testing Other-Regarding Preferences in Sociopaths	Ming Hsu, Eric Set, Alexander Slade, Edelyn Verona
19	Reward Sensitivity for Self and Others	R. McKell Carter, Elizabeth T. Cirulli, John A. Clithero, Justin Meyer, O'Dhaniel A. Mullette-Gillman, David V. Smith, Adrienne Taren, Vinod Venkatraman, David B. Goldstein, Michael L. Platt, J.H. Pate Skeene, and Scott A. Huettel
20	The vmPFC is involved in making decisions for self and other	Vanessa Janowski, Colin Camerer, Antonio Rangel
21	Using neurometrics of value to solve the public goods free-rider problem	Ian Krajbich, Colin Camerer, John Ledyard, Antonio Rangel
22	Reward and associative learning in the posterior cingulate cortex	S. R. Heilbronner, and M. L. Platt
23	On the Pertinence of Reinforcement Learning for Risk Control	A.D.Nursimulu, K.Preuschoff P.Bossaerts
24	Neural Mechanisms of Social Learning and Cognitive Imitation	C. J. Burke, P. N. Tobler, M. Baddeley & W. Schultz
25	A psychometric-neurometric comparison of subjective value in vmPFC during decision under risk	Shih-Wei Wu, Shinsuke Shimojo, John O'Doherty, Paul Glimcher, Antonio Rangel
26	Sleep related changes in attribute recall and choice	U.R. Karmarkar, R. M. C. Spencer, and B. Shiv
27	A Salesforce-Specific Theory of Mind Scale: Tests of Its Validity by Multitrait-Multimethod Matrix, Confirmatory Factor Analysis, Structural Equation Models, and Functional MRI	Carolyn Yoon, Roeland C. Dietvorst, Willem J. M. I. Verbeke, Richard P. Bagozzi, Marion Smits, and Aad van der Lugt

28	So close and so much invested: Goal proximity and sunk effort escalate frustration	Rongjun Yu, Dean Mobbs, Ben Seymour, James Rowe, Andrew J Calder
29	Medial prefrontal cortex mediates the competitive component of social decision making	Nadège Bault, Mateus Joffily, Aldo Rustichini, and Giorgio Coricelli
30	The Influence of Communication on Non-Interpersonal Trust: The Case of eBay	M. Hubert, R. Riedl, P. Kenning
31	Shared neural substrates for social and non-social reward processing	Alice Lin, Ralph Adolphs, and Antonio Rangel
32	Propensity for selfish behavior in the dictator game is affected by frame-order parsing	A. E. Pereira
33	Social Decision-Making in the Elderly	David R. Roalf, Mahria R. Lebow, Suzanne H. Mitchell, William T. Harbaugh & Jeri S. Janowsky
34	Mechanisms of Social and Non-social Framing Effects	David V. Smith, Vinod Venkatraman, R. McKell Carter, Justin R. Meyer, John A. Clithero, J. H. Pate Skene, Michael L. Platt1, Scott A. Huettel
35	Trust games – are effort and money equivalent?	I. Vilares, G. Dam and K. Kording
36	Neural reactions to inequity	Bernd Weber, Klaus Fliessbach,Jan-Christoph Schoene-Bake, Peter Trautner, Marieke Schnabel, Courtney Philips, Christian Elger, Armin Falk

Evaluating the “prominent deck B phenomenon” of the Iowa Gambling Task under the two payment procedures of gain and loss in an extended series of 300 trials

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Objective: The Iowa gambling task (IGT) uses a number of steps to simulate a real-life situation with uncertainty and a complicated instruction and payment is administered, such as a concurrent payment of both $100 gain and $150 loss within a trial across the whole series of 100 trials. However, a number of studies have identified some validity problems in the IGT. For example, the “prominent deck B phenomenon” that is difficult to explain under the original scheme of IGT, was revealed by more and more research groups (Lin et al. 2007). This study experimentally tests the “prominent deck B phenomenon” with two major modifications. The first modification is to examine if the phenomenon and/or a myopia of long-term outcome still exist in an extended session of 300 trials. The second modification concerns with a comparison of the original concurrent payment of gain and loss in some selected trials (henceforth, Concurrent Version or cIGT) and a revised net payment mode by summating the original gain and loss in the trial (Net Version or nIGT).

Methods: In total, 48 college students (24 females and 24 males) were randomly assigned to two groups. Subjects in first group (12 females and 12 males) played the Net Version (nIGT), in which subjects received one monetary feedback during each trial (only the net gain or loss). Subjects in second group (12 females and 12 males) played the Concurrent Version (cIGT), in which subjects received one or two monetary feedbacks during each trial (always has a gain when it has a loss in some selected trials). To verify the learning effect, this study conducted 300 trials of the IGT (3 times the standard IGT) to monitor the lasting learning curve.

Results: Empirical results demonstrate that no significant differences (t-test, df(23)) existed among choice pattern in the nIGT and cIGT$(A_{n-c}{:}p=.61;\ B_{n-c}{:}p=.21;\ C_{n-c}{:}p=.15;\ D_{n-c}{:}p=.76)$. Most subjects preferred decks B, C and D over deck A in both versions across an extended series of 300 trials. The “prominent deck B phenomenon” was again revealed in both nIGT and cIGT.

Conclusions: Insignificant differences between cIGT and nIGT may indicate a strategy of net calculation was adopted by the subject irrespective of the payment procedures. Over the 300 trials of both IGT versions, the prominent deck B phenomenon (Lin *et al*., 2007; Ahn *et al*., 2008), which runs counter to the basic IGT assumption that decks are chosen based on long-term outcome, is still observed even under an extended series of 300 trials. This may indicate a myopia of long-term outcome still exists even after a long exposure of uncertainty condition.

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Comparing the uncertainty effects of two payment procedures under an extended series of 300 trials in the Soochow Gambling Task

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Objective: The Iowa gambling task (IGT) has been utilized in over 250 neurological, psychiatric studies and so on. This task was not only a research task, it has been a neuropsychological assessment test for 13 mental disorders. However, many researchers argue against the basic assumption of the IGT and its supporting theory—the Somatic Marker Hypothesis (SMH). One argument was elucidated by Chiu *et al.* (2008), who developed a modified version of the IGT, namely, the Soochow Gambling Task (SGT), and demonstrated that normal decision-makers are guided by gain-loss frequency, not by long-term outcome. However, the SGT has one procedure that differs from that in the original IGT. In the SGT, a subject always receives a gain or loss in each trial (a net payment, or a Net Version), whereas in the IGT, a subject is generally given gain feedback after each card selection and only sometimes with an additional loss in a single trial (a concurrent payment of both gain and loss, or a Concurrent Version). Thus, the SGT may be considered not as uncertain as the original IGT. To mimic the original concurrent payment in the IGT, the present study investigated a comparison between the net payment of SGT (Net Version, nSGT) and a mimic concurrent payment of SGT (Concurrent Version, cSGT) and tested under an extended series of 300 trials.

Methods: To clarify this question, 48 college students were enrolled in this study. In total, 24 subjects (12 females, 12 males) performed the original SGT (net payment, nSGT) and the other 24 subjects (12 females, 12 males) performed the concurrent payment SGT (cSGT). Each subject played 300 SGT trials on a computer. In both versions of the SGT, decks A and B result in a loss of \$500 over 10 trials. Conversely, decks C and D result in a gain of \$500 over 10 trials.

Results: Experimental results indicate that the two versions of the SGT did not differ significantly *(F(1,23)=.00, p=1.00)*. However, over 300 trials of the nSGT, most subjects gradually began to avoid bad decks A and B in favor of decks C and B. However, in the cSGT, subjects learned very slowly, even near the end of the 300 trials.

Conclusions: The choice behavior under nSGT and cSGT are supposed to experience the same degree of uncertainty. However, subjects seem to have more difficulty learning the internal rules of cSGT than of nSGT. Namely, decision makers are difficult to hunch the long-term outcome in cSGT rather than in nSGT under the 300-trials situation.

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Examining the validity in the clinical version of Iowa Gambling Task

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Objective: For more than a decade, the Iowa gambling task (IGT) has been utilized to test numerous mental deficits induced by neurological damage or psychiatric disorders. The IGT has recently been standardized for testing 13 different neuropsychological disorders. Moreover, the IGT is now published and sold by the PAR, Inc., as a neuropsychological test. However, this test has many problems that must be resolved. The "prominent deck B phenomenon" may be the most serious problems associated with the IGT. This phenomenon in growing number of IGT studies indicates that normal decision-makers prefer bad deck B. Choice behavior in the IGT can be interpreted by gain-loss frequency rather than inferring future consequences. However, no experiment evidence has demonstrated that the "prominent deck B phenomenon" exists in the clinical IGT.

Methods: In total, 72 participants (35 males and 37 females) performed the clinical version of IGT (2006). Each subject performed the computerized clinical-version 3 runs; that is, 300 trails (3 runs x 100 trials) were run to assess the extended preference of subjects in the clinical version of IGT.

Results: Long-term outcome (decks C and D *vs*. A and B) ($F(1,71)=30.97, P<.01$) and gain-loss frequency (decks B and D *vs*. A and C) ($F(1,71)=31.35, P<.01$) were significant. However, the "prominent deck B phenomenon" was observed during each run of the clinical version. Bad deck B was chosen nearly as frequently as good decks C and D, and significantly more than A, even during the third run.

Conclusions: Experimental results suggest that the "prominent deck B phenomenon" existed in the clinical version of IGT. The existence of the "prominent deck B phenomenon" means that gain-loss frequency was the primary guiding factor for decision-makers, not long-term outcome. Therefore, those using the IGT should be very careful when interpreting patient results during assessment.

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Reexamining the Aging Effect in the Iowa Gambling Task

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Objective: The Iowa gambling task (IGT) is extensively adopted as a diagnostic test for several neurological disorders. However, task validity remains contentious. For instance, the aging effect on real-life decisions is contested. For instance, McPherson *et al*. (2002) pointed out that no significant difference exists between elders and the young in the IGT. However, Denburg *et al*. (2005, 2006) and Fein *et al*. (2007) suggested that the performance of elderly was poorer than that of the young in the IGT. Thus, whether the IGT can distinguish between decision patterns of the old and young remains unknown.

Methods: This study recruited 48 subjects aged 50–96 years old and 48 college students aged 18–22 years. All subjects performed the computerized version of the IGT. The age range of those over 50 in this study is relatively larger than that in previous studies. The male to female ratio was balanced in and between groups. Each subject performed 100 trials of the game. Some of those over 50 who had never used a computer and mouse were asked to use a finger to point to the decks they chose on the screen and an experimenter helped him/her turn cards.

Results: This empirical study identified an age effect ($F(3, 90)= 3.769, P<.05$); however, the greatest difference between the young and old was focused on bad decks A ($t(47)= 3.47, P<.01$) and B($t(47)=-2.37, P<.05$). Most subjects in both groups preferred decks B, C, and D over deck A. The mean number of cards chosen by the elder group was A (20.71), B (28.35), C (25.96), and D (24.98), and that for the younger group was A (16.6), B (32.90), C (24.31), D (26.19). However, the "prominent deck B phenomenon" was observed in both groups. In summary, those aged over 50 years had an average choice pattern for the four decks (close to the chance level) than that of the younger group. Those over 50 chose bad deck A more than did the young, and chose bad deck B less than did the young.

Conclusions: This study demonstrates that most over 50 chose the four decks nearly average; however, the young were relatively easily influenced by the internal gain-loss structure of the IGT. This analytical result may imply that the young were sensitive to gain-loss frequency than the older subjects under uncertainty.

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Retesting the somatic feedback induced by caffeine in the Iowa Gambling Task

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Objective: The Somatic Marker Hypothesis (SMH) suggests that peripheral somatic feedback (bodily loop) is crucial when making decisions. Bechara *et al*. (1997, 1999) demonstrated that healthy decision-makers can infer long-term outcome with the help of somatic signals. However, North and O'Carroll (2001) and O'Carroll and Papps (2003) manipulated somatic signals, indicating that changing the somatic signal did not influence decision-maker performance in the Iowa gambling task (IGT). Furthermore, Killgore *et al*. (2007) demonstrated that caffeine did not improve the risk behavior induced by sleep deprivation in the IGT. However, Killgore *et al*. did not use a control group that was not deprived of sleep. Therefore, this study experimentally tests the Killgore et al. study with a group without the sleep deprivation, but with the caffeine.

Methods: The caffeine group had 25 subjects (12 males and 13 females) and the control group had 25 subjects (12 males and 13 females). Each subject of caffeine group drank a cup of coffee (320 ml, caffeine concentration: 68mg/100 ml,). Each subject of control group drank some water or nothing over a 30-min period. The brand of coffee was unknown to subjects. After imbibing their respective liquids, each subject performed the computerized version of the IGT.

Results: Experimental results indicate that no significant difference (t-test, df(24)) exists between the two groups in terms of IGT performance $(A_{co\text{-}ca}{:}p{=}.95;\ B_{co\text{-}ca}{:}p{=}.84;\ C_{co\text{-}ca}{:}p{=}.36;\ D_{co\text{-}ca}{:}p{=}.30)$. Namely, caffeine did not enhance or disturb subject preference for good decks C and D. However, the outcome of was insignificant for both groups ($F(1,24)=.02,\ P=.89$); however, the frequency effect was significant ($F(1,24)=25.36,\ P<.01$) as most subjects preferred bad deck B, which is consistent with "prominent deck B phenomenon" suggested by Lin *et al.* (2007).

Conclusions: Experimental results suggest the caffeine did not improve decision-maker behavior in the sleep-deprived group (Killgore *et al*., 2007). This experimental result may support the findings by North and O'Carroll (2001) and O'Carroll and Papps, indicating (2003) that somatic signal change is not correlated with decision-making in the IGT. Nevertheless, the effect of gain-loss frequency (Chiu *et al*., 2008) was predominant in this study.

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Decision-making in the Iowa and Soochow gambling tasks by Patients on Methadone Therapy

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Objective: Bechara *et al.* (2001) suggested that the Iowa gambling task (IGT) is sufficiently sensitive to distinguish between decision patterns of subjects with ventromedial prefrontal lesions, those with substance dependencies (SD) and normal controls. However, an increasing number of studies failed to replicate the original findings for the IGT (1994) and researchers have started questioning the validity of the IGT (Fernie *et al*., 2007; Lin *et al*., 2008; Ahn *et al*., 2008). Furthermore, Chiu *et al.* (2005, 2008), who utilized the Soochow gambling task (SGT) to test normal decision-makers, suggested that under uncertainty, subjects were guided by immediate gain or loss, not long-term outcome. Thus, this study conducted an experiment to verify the power of the IGT and SGT to assess those with SD, who may lack impulse control.

Methods: This study recruited 27 heroin users who were on methadone therapy. Subjects played the computerized versions of the IGT and SGT. All subjects provided informed consent and spent 15–20 min playing the two computer games before taking the methadone. This behavioral test was approved by the IRB of the Beitou Armed Forces Hospital. A questionnaire was used to assess the total and extended preferences on the explicit level after each game.

Results: IGT results indicate that the bad decks A and B was not significant highly chose then good decks C and D ($F(1,26)=3.89,\ P=.059$). Most SD subjects preferred bad deck B over the other three decks. The SD subjects gradually increased their preference for deck B and avoided bad deck A as the game progressed. Conversely, SD subjects preferred bad deck A over the other three decks in the SGT and the effect of long-term outcome (gain-loss frequency) was significant ($F(1,24)=7.15,\ P<.05$). The learning curve indicated that SD subjects preferred the good final-outcome decks (C,D) gradually. In fact, SD subjects' choice patterns were similar to that of normal subjects in previous IGT (with "prominent deck B phenomenon") and SGT studies (Chiu et al., 2008; Ahn et al. 2008).

Conclusions: The Bechara et al. (2001) finding is not supported here. Experimental results indicate that the preference for bad decks B of SD subjects can be explained by myopia to long-term outcome or hypersensitivity to immediate gain in the IGT. However, SD subjects gradually learned to favor long-term outcome (good decks C and D) by the end of SGT; this finding is inconsistent with the basic assumption of the IGT.

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An fMRI Study of Reward Processing in Methamphetamine Users

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Objectives: Drugs of abuse such as methamphetamine lead to a stepwise neurobiological distortion of the reward circuitry. Functional magnetic resonance imaging (fMRI) studies of reward processing, such as those using the Monetary Incentive Delay (MID) task, have described the neural correlates of aspects of the reward response under various contingencies. In this study, we applied the MID task to study the reward circuitry in chronic methamphetamine users.

Methods: We analyzed fMRI data acquired during the performance of the MID task from 8 abstinent chronic methamphetamine users (MA) and 4 healthy controls (HC). Differences in fMRI signal during the anticipatory period of no reward trials ($0) and positive (win $5) or negative (avoid losing $5) monetary reward trials were compared between groups.

Results: Group differences were as follows. For HC participants, positive reward trials were associated with decreased activation in anterior insula and putamen, but increased activation in medial prefrontal cortex (mPFC) and frontopolar regions, whereas MA participants exhibited decreased activation in hippocampus and posterior cingulate cortex and increased activation in caudate and anterior cingulate cortex (ACC). Negative reward trials were associated with increased activation in ACC and superior temporal gyrus in HC participants, and increased activation in caudate but decreased activation in mPFC in MA participants.

Conclusions: Consistent with current neurobiological models of addiction that implicate the dorsal striatum in the consolidation of addictive behaviors, our findings suggest that methamphetamine users have altered neural processing during the anticipation of rewards, characterized by over-engagement of dorsal striatal regions (but impaired engagement of the ventral striatum in individual group analyses) at the expense of engagement of prefrontal regions. Future directions include analyzing differences in fronto-striatal circuits during the consummatory phase of the reward response, as well as increasing the number of participants in our study.

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Preliminary results from an fMRI investigation of self-control over cigarette smoking

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In the present study we sought to develop a method for investigating neural substrates of self-control over a highly valued and immediately available reward. Functional Magnetic Resonance Imaging was combined with an MRI compatible device for delivering nicotinic vapor ("electronic cigarette".) Thirteen nicotine-addicted participants were scanned while they engaged in a smoking self-control challenge after overnight abstinence from nicotine. Participants watched smoking-related video clips with a tube in their mouths allowing them access to nicotinic vapor from an electronic cigarette. After some clips, a valve on the tube was opened to permit them to inhale the vapor (Smoke Available), while on other clips, the valve remained closed, making smoking impossible (Smoke Unavailable). Participants had been instructed to "try not to smoke on as many of the 'Smoke Available' rounds as you can manage." Craving ratings were recorded on each trial.

Mean craving across participants was 3.24 ± 1.1 on a 5-point scale. Participants abstained on 79.4% of trials in which smoke was available. When comparing these successful self-control trials with trials in which smoke was not available (controlling for participants' reported craving) BOLD activation was greater in numerous brain regions including the superior frontal gyrus, supplementary motor area, orbitofrontal cortex, ventromedial prefrontal cortex, and middle frontal gyrus as well as in the caudate and putamen. These data demonstrate that voluntary abstinence (relative to externally determined abstinence) is associated with increased activity in a broad network of frontal and striatal regions. The data also provide validation of the present methodology for investigating the neural substrates of self-control.

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Financial and Psychological Risk Attitudes Associated with Two Single Nucleotide Polymorphisms in the Nicotine Receptor (CHRNA4) Gene

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Abstract

Motivation: With recent advances in understanding of the neuroscience of risk taking, attention is now turning to genetic factors that may contribute to individual heterogeneity in risk attitudes.

Objective: We test for genetic associations with risk attitude measures derived from both the psychology and economics literature, examining single nucleotide polymorphisms (SNPs) in a spectrum of candidate genes that affect neurotransmitter systems influencing dopamine regulation or in genes thought to be associated with risk attitudes or impulsive disorders.

Methods: Subjects (N=67) provided blood samples for genotyping, participated in a financially-binding experiment designed to assess financial risk tolerance and provided responses necessary to assess the psychological risk attitudes of Harm Avoidance (HA) and Novelty Seeking (NS). The genetic association tests used both a dominant and a recessive model for each SNP and phenotype considered. The false discovery rate p-value is used to correct for multiple testing.

Results: Risk attitude measures from economic and psychology literatures are not strongly correlated. Furthermore, two SNPs in the gene encoding the alpha 4 nicotine receptor (*CHRNA4*, rs4603829 and rs4522666) are associated with HA. The rs4603829 SNP, which is located in the 3' region, has not been associated previously with a phenotype. NS is associated with several Catechol-*O*-methyl transferase SNPs while financial risk tolerance measures are associated with several Vesicular Monoamine Transporter SNPs, but the significance of these associations did not withstand statistical adjustment for multiple testing.

Discussion: Neuronal nicotinic cholinergic receptors, including *CHRNA4*, are of general interest because they modulate the release of several neurotransmitters, including dopamine, serotonin, gamma-amino butyric acid and glutamate in the ventral tegmental area. *CHRNA4* is highly expressed in the central nervous system and is, in particular, important in modulation of mesolimbic dopamine function, which suggests it is an appropriate target for studies concerning reward processing and risk attitudes.

Conclusions: Our findings suggest an improved understanding of the genetic basis of risk attitudes must consider the range of methods available for measuring risk attitudes and look beyond the traditional direct focus on dopamine and serotonin receptor and transporter genes. A replication of the study involving a larger sample has completed data collection and blood sampling stages; genotyping and association tests are planned for the summer of 2009 and may be available for discussion by the meeting date.

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Preference is more than just liking: an fMRI study of food preference

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Objective: Several neuroimaging studies have examined brain activations during choice behavior. However, previous studies leave unclear whether activations reflect processes involved in comparing and deciding between potential rewards or simply reflect the process of evaluating liking, because choice decisions were not contrasted with simple ratings of liking. In order to isolate brain regions involved in the actual comparison and decision process, we performed fMRI in healthy subjects while they chose between two foods versus when they made liking ratings of a single food.

Methods: 12 healthy adults participated in this two-part study. During the first session, subjects rated how much they liked a variety of foods. During the second session, they viewed pictures of foods and on separate trials rated either how much they liked the food (same picture on both sides of the screen) or how much they preferred one of two food items (different picture on either side of the screen), while being scanned using fMRI. Scanning was accomplished on a 3T Phillips scanner with a thin slice protocol optimized to limit signal dropout in the orbitifrontal and amygdala region.

Results: Preference trials were associated with more activation than liking trials in the left amygdala/piriform cortex, the right amygdala, the right putamen, and the right posterior insula. Subjects responded significantly faster on liking trials than preference trials.

Conclusions: This study provides evidence that a number of brain regions are involved in the process of comparing and choosing between potential rewards. The amygdalar activations are particularly interesting in that it has been previously suggested that the amygdala helps determine the hedonic value of stimuli. However, the present data suggest that it may additionally play a role in decision making that extends beyond a simple evaluation of liking.

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The Sweet Side of Sugar: The Effect of Raised Insulin Levels on Price Fairness Judgments

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Objective: Recent studies revealed the role of hormones for interpersonal trust and fairness. However, less is known about the role of hormones on non-interpersonal trust and fairness. We tested the hypothesis that raised insulin levels (supposed to stimulate the hormone serotonin) change non-interpersonal fairness judgments of individuals.

Methods: Thirty-seven adult subjects (divided into three groups) participated in our study. Each subject had to evaluate the predefined (real) price of 48 convenience products as fair, alternatively making their personal fair price judgment provided a rejection of the real price. Subjects of the experimental group were manipulated using 90 grams of pharmaceutical glucose drained in 0.3 l of sparkling water. Control group I had to drink 0.3 l sparkling water without any manipulation. Control group II was not manipulated at all. Study design for every subject followed precisely the insulin release curve of a healthy adult metabolic subject to match the hypothetical insulin level of the subjects to their respective response behavior. For the statistical analysis of our data we used a simple independent t-test including "Levene`s Test". Normal distribution condition was examined with the Shapiro-Wilk-Test. Following the insulin release curve we analyzed fair price judgments given by the participants in the first ten minutes (1st interval, first peak of insulin release curve) respectively after 40 minutes (2nd interval, second peak of insulin release curve). The average price differences were calculated as a spread of the real price and fair price judgment.

Results: As expected, subjects in the experimental group evaluated prices significantly more fair than in the control groups within the first 10 minutes (1st interval) [experimental group/control group 1: t-value: 3.44; $p < 0.01$; experimental group/control group 2: t-value: 2.66; $p < 0.05$] Significant differences between the two control groups were nonexistent. Thus subjects in both control groups rejected higher price-levels while the experimental group accepted higher prices. However, 40 minutes after glucose manipulation (2nd interval) these effects diminished. Side effects of glucose manipulation could not be observed.

Conclusions: Our study provided first insights into the role of raised insulin levels on non-interpersonal, abstract fairness. We found that non-interpersonal (price) fairness changed after glucose manipulation. The estimated effects confirm our assumption that glucose manipulation finally results in behavioral changes relevant for non-interpersonal fairness.

Comparing The Expected Subjective Values of Primary and Monetary Rewards

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Objective: Several studies have investigated expected utility (EU) in behavior, or its neural correlate expected subjective value (ESV), in brain activity of humans. Some studies even examined the risk aversion for money as a primary tool for estimating EU and ESV, but no study has directly compared EU and ESV of food, water and money within individual choosers.

Methods: Human subjects fasted for four hours before conducting the experiment. Money and two primary rewards (food and water) were offered to the subjects. In the same reward lotteries, subjects were asked to choose between a sure win of a small amount of that reward and a probability of either winning a larger amount of the same reward or getting nothing. In the mixed-reward type lotteries, subjects had to choose between a sure win of a small amount of money and a probability of either winning a high amount of food or water or getting nothing. For each reward type, five different winning probabilities were used at five different amounts. Each choice option was repeated six times. One choice option from each reward type was realized at the end of the experiment and was actually played for real money and real primary rewards. After the end of the experiment subjects had to stay in the lab for an additional two hours and the only food and drink they were allowed to consume was what they have won in the selected trials.

Results and Conclusions: We used methods from experimental economics to evaluate the EU of money, food and water for each subject. From the mixed reward type blocks we computed the relative pricing between the different reward types. Individual subjects were uniformly risk-averse over monetary lotteries as has been reported previously, although individual subjects showed highly different degrees of risk aversion. We found that subjects were also uniformly risk-averse over lotteries that involved rewards of food and water. Translating these degrees of risk aversion into the language of utility, we found that for our subjects the subjective values of food, water and money all grew as a compressive function of objective value. Interestingly, the utility functions measured across reward types were highly correlated within individuals – a subject who was highly risk averse for money was very likely to be highly risk averse for food and water, although there was an overall trend towards lower degrees of risk aversion for money as compared to primary rewards. Next, we plan be to use fMRI to identify the neural correlates of ESV for each of these classes of reward. We hypothesize that the activation in some brain areas like the medial PFC and striatum will track the ESV for all reward types, but that there will be other brain areas that will track the ESV of only a specific reward type.

The role of anterior cingulate cortex in self-control

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Objective: Self-control is the executive process by which decision-makers inhibit the impulse to commit an action that is immediately rewarding but ultimately detrimental. Successful self-control is thought to involve the frontal cortex, including the anterior cingulate, orbitofrontal, and lateral prefrontal cortices. Nonetheless, the precise mechanisms of self-control remain unknown.

Methods: We recorded both behavior and single-unit responses from two male rhesus monkeys. We have developed a novel task to study the neural mechanisms of self-control in rhesus monkeys. In this task, monkeys must maintain gaze on a central spot. Occasionally, a distracting image appears at an unpredictable time in the periphery. Saccades to this image lead to small, immediate rewards, and are considered failures of self-control. Maintaining gaze leads to a larger reward at an unpredictable, later time, and is considered successful self-control.

Results: We find that monkeys' behavior consists of a mix of successes and failures, and that failures often occur well after the tempting image appears, suggesting that this task provides a good model of self-control. We also found that neuronal responses in anterior cingulate cortex are tonically enhanced before, during, and after trials associated with failures of self-control. We did not observe any difference in perisaccadic activity on the two types of trials.

Conclusions: These data suggest that ACC contributes to ongoing levels of self-control, and registers the consequences of such failures, but does not directly contribute to the decision-making processes that directly cause failures of self-control.

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The influence of extrinsic rewards on intrinsic motivation

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Objective: Psychological and economic theories assume that extrinsic rewards can 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 reward circuitry after monetary rewards compared to when there was no extrinsic motivation. We hypothesize the opposite for verbal reinforcement: Here, activation should be higher than or the same as when no extrinsic reward was provided before.

Methods: Forty-five subjects will participate in our functional magnetic resonance imaging (fMRI) experiment, which consists of three parts. In part 1, each subject will solve a series of puzzles (finding the number of differences between two pictures) without receiving any reward for solving a puzzle correctly. In part 2, one third of the subjects will go on doing the task without any reward (treatment 1), one third will receive a monetary reward for every puzzle they solved correctly (treatment 2), and one third will receive verbal reinforcement for every puzzle they solved correctly (treatment 3). In part 3, all subjects will do another series of puzzles without receiving an extrinsic reward. All subjects will further receive a show-up fee independently of their performance.

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. First results will be presented.

Individual Differences in Anticipation of Distinct Reward Categories

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Objective: Humans are individually responsive to a wide range of rewards. Although prior research has established the effects of context, such as satiety, on sensitivity to different types of reward, the role of individual differences in shaping neural reward circuitry remains unclear. Given the contributions of variability in reward sensitivity to behavior, elucidating the biological mechanisms of individual differences in reward processing can lead to a better understanding of both normal and pathological variability in motivated behavior.

Methods: 63 subjects (31 female, all self-reported Caucasian) participated in the study. Neural data was collected using event-related functional magnetic resonance imaging (fMRI). In order to reliably engage 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. Finally, subjects received feedback on whether they responded in time and, if so, that they would receive the corresponding reward at the end of the experiment. Saliva samples were also collected so that individual variation in genetic contributions to reward processing could be identified.

Results: Consistent with the existing literature, we found that reward anticipation robustly increased blood-oxygenation-level dependent (BOLD) signal in ventral striatum and subregions of prefrontal cortex. This anticipatory activation was common across both reward modalities, both within and across subjects. Additionally, we found that individual measures of inferred preference and motivation for candy and money tracked BOLD signal in both the striatum and insular cortex.

Conclusions: These preliminary results indicate that reward anticipation shares a common neural substrate across multiple reward modalities. However, within this common substrate, we found evidence for individual variation in motivation for primary and secondary rewards that is likely to have genetic underpinnings. Identifying the neural underpinnings of these differences can help illuminate the mechanisms through which they impact behavior, with potential implications for a wide range of phenomena, from saving patterns to addiction.

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The economics of physical effort

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Objective: We introduce a novel experimental paradigm where we measure participants' utility for money by assessing their willingness to perform physical effort for money. Previous approaches for measuring utility have relied on monetary gambles. This requires participants to make judgments about the probability of possible outcomes and it is known that such estimates may be biased. The experimental paradigm presented here measures utility directly without the use of lotteries. We measure utility in terms of an ethologically meaningful and physiologically relevant unit - energy expenditure.

Methods: Eighteen participants were presented with a sequence of movement choices. Small arm movements were associated with small rewards or large punishments, and larger movements with larger rewards or smaller punishments. Movements were made energetically costly by the use of a robotic device that rendered resistive forces. Differences in participants' willingness to move thus depended only on the utility they associated with the amount of money at stake and the associated movement costs. From a sequence of movement choices we are able to infer participants' utility function in terms of energy expenditure.

Results: Participants are willing to work harder (expend more energy) when large monetary amounts are at stake. Utility is concave (diminishing returns), in that individuals were willing to work less than twice as hard for twice the amount of money. Lastly, participants demonstrate loss aversion by exerting more effort to avoid losses than to obtain equivalent monetary gains.

Conclusions: From movement effort decisions, we have inferred utility functions with diminishing-returns and loss-aversion. Our findings suggest that people assign utility in similar fashion across very different decision tasks.

The Neural Basis of Other-Regarding Preferences

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Individuals place different values on goods that can benefit others. For example, someone might be willing to contribute money to the United Way but not to the National Rifle Association. To study this variability in other-regarding preferences, and to relate them to self-regarding preferences, we engaged human subjects in a set of behavioral experiments.

To assess subjects' self-regarding preferences, we engaged them in choice situations involving certain and uncertain monetary outcomes for themselves only. To assess other-regarding preferences, and their variability, we use a variant of the dictator game that systematically varies the price of contributing money to a needy classroom and the topic taught in the classroom (we use the site DonorsChoose.org, a charity that facilitates monetary donations to needy classrooms.). As in all economic experiments, there is no deception and choices are incentive compatible: at the conclusion of the experiment one choice situation is selected at random and realized for payment so that subjects treat each as though it counts for actual payment. Also, because of the potential for induced demand effects in other regarding preferences (e.g. social desirability bias), we conduct both *anonymous* and *confidential* versions of the experiment. In the anonymous version a mapping between subject identification numbers and subject names never exists, while in the confidential version subjects put their name and contact information on their ID card.

We find: (1) Much lower overall contribution rates than those previously reported in the neuroeconomic literature, a finding we attribute to our anonymity and confidentiality controls. (2) No apparent difference in behavior between anonymous and confidential versions of our behavioral experiment, a critical finding since MRI data collection can never credibly be considered anonymous. (3) The strength of other-regarding preferences is modulated by the topic taught in the classroom to which contributions would go: Subjects reliably contribute more money to classrooms teaching mathematics than to those teaching other topics.

These data thus provide two kinds of evidence about other-regarding preferences. First, they provide a detailed economic portrait of other-regarding preferences and how they relate to self-regarding preferences in a large group of individuals. Second, the fact that we can describe multiple classes of other-regarding preferences, and relate them to self-regarding preferences, means that we can examine how other-regarding preferences are modulated by the identity of the recipient. These measures should allow an ongoing functional magnetic resonance study to reveal both what is neurally unique about other-regarding preferences and, where in the brain modulations in the intensities (or ordinal ranks) of these preferences arise.

Testing Other-Regarding Preferences in Sociopaths

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Studies of other-regarding preferences have found that people are concerned with equity and total social welfare. People are also motivated by reciprocity, rewarding kindness or punishing unfair behavior, even at personal loss. We study the degree to which these dimensions of other-regarding preferences are tied together by running a range of simple games comparing behavior of a group of individuals who have been clinically assessed as scoring either high or low on the Hare Psychopathy Checklist-Revised, a clinical diagnostic tool used to rate a person's psychopathic or anti-social tendencies.

Our subject pool consists of male subjects, all of whom are former prison inmates. The experimental group were those who scored high to very high on psychopathy (often referred to as sociopathy). Members scoring in the low to very low range served as a comparison population. Data on past criminal history, family background, and other test scores were collected for a related study on each subject.

Due to safety requirements governing any work with these subjects, behavioral data was collected in one-on-one sessions. Four types of games were used. Subjects completed twelve rounds of a binary forced-choice dictator game. They were then allowed to take an unexpected exit possibility (Dana et al. 2006). Subjects also completed a pure distribution game, in which subjects make choices regarding other players' payoffs, and a two-person response game as both proposer and responder (Charness and Rabin 2002). We based payment on their choice in one round of each game and, for the two-player response game, the corresponding choice of the previously interviewed subject, including subjects used in pilot sessions.

We hypothesize that these emotional and social deficiencies will affect other-regarding preferences in systematic ways. Of particular interest is whether members of the experimental group are differentially sensitive to concerns for inequity, social welfare, and reciprocity. Payoff values were set to allow the estimation of these parameters, similar to that of Charness and Rabin. Finally, we also test for the presence of "perverse" preferences using a series of catch trials in the experiment.

In addition to testing questions of theoretical interest, our study adds to ongoing policy discussion regarding the penal system, in which a disproportionate number of prisoners for violent offenses are diagnosed with psychological deficits similar to our subjects. By identifying whether or not such people have perverse preferences or are simply unable to comprehend the intentions or feelings of others, we may contribute to questions in ethics and criminology, in which such notions may imply differing degrees of guilt.

Reward Sensitivity for Self and Others

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Objective: Making a decision during game play requires a neural representation of potential rewards for both oneself and the other individuals involved. In some circumstances, rewards for others have found to be processed similarly to rewards for self. However, it is not sufficient to have potential rewards for both self and others represented in the same neural circuitry. In order to make a decision, a mechanism for attributing a reward to another individual is necessary. We sought to identify differences in reward representation for self and others common across participants and as trait differences between participants.

Methods: Functional magnetic resonance imaging (fMRI) was used to acquire blood-oxygenation-level dependent (BOLD) data in sixty two adult participants of self-reported Caucasian ancestry during a passive reward task. Participants viewed a series of risky gambles with a probability (min. 0.11; max. 0.89) of winning a prize ranging in value from $12 and $40 for either themselves or a chosen charity. Each gamble was presented for an average of three seconds before the gamble outcome was presented. At the conclusion of the experiment, participants were paid for one randomly selected gamble. Our regressors modeled the gamble presentation, and outcome wins and losses for both charity and self. We also collected a number of behavioral measures of individual attitude toward risk and reward as well as saliva samples for genetic analysis, allowing the further examination of individual differences in the representation of reward for others.

Results: Primary regressors for the initial presentation of the risky gamble, for both self and charity, covary significantly with activation in areas normally associated with the risk including posterior parietal cortex, inferior frontal gyrus, and insula. Examination of activity during gamble outcome presentation reveals significant activation in areas normally associated with reward including ventral striatum and medial prefrontal cortex for both self and charity treatments.

Conclusions: Preliminary analysis indicates BOLD patterns of activation for our passive task are similar to past results for both active and passive receipt of reward. Covariates of individual differences in both behavior and genetics will be examined in future analyses.

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The vmPFC is involved in making decisions for self and other

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Every day we make decisions that affect others, and we typically seek to choose the option that maximizes their preferences. We hypothesized that solving this type of decision is likely to involve an interaction between the decision making and mentalizing circuitries. In particular, based on previous results on goal-directed choices for the self, we hypothesized that common regions of the ventro-medial prefrontal cortex (vmPFC) would encode value signals at the time of decision regardless of whether the choice was for self or for other. We also hypothesized that when choosing for other, but not for self, the value signals in the vmPFC would be modulated for areas such as the temporal pole, superior temporal sulcus, temporoparietal junction (TPJ), and insula, which have been found to play key roles in social tasks involving mentalizing.

To test these hypotheses, we used human fMRI while subjects performed a simple task using a Becker-DeGroot-Marshack auction in which they purchased goods in one of two conditions: a) purchases for self paid with one's own funds, or b) purchases for other paid with the other's funds. One of the advantages of this task is that the bids entered in the auction provide a good measure of the value assigned by the subject to the different objects at the time of decision.

In line with the first hypothesis, we found that overlapping areas of the vmPFC encoded for both the values for oneself and the values for other. In line with the second hypothesis, we found that the areas of the vmPFC encoding for value exhibit functional connectivity with the anterior insula and anterior cingulate, as measured by a psychophysiological interactions analysis. However, contrary to our expectations, the TPJ did not exhibit differential activation or connectivity when choosing for self and other.

These results suggest that social decision-making may recruit the same basic valuation network that is used in individual choice but that areas involved in various aspects of social cognition might modulate these areas.

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Using neurometrics of value to solve the public goods free-rider problem

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Every group needs to decide when to provide public goods and how to allocate the costs. In an ideal arrangement, individuals would reveal their values for the public good to the government, the socially optimal level of the good would be implemented, and the costs would be fully paid using fees that are proportional to individual benefits. Unfortunately, the economic theory of mechanism design has shown that this ideal solution is not possible when the government lacks knowledge about the individual valuations. We show that this impossibility result can be overcome in experimental settings by combining technologies for obtaining neural measures of value (fMRI-based pattern classification) with carefully designed economic incentives.

Reward and associative learning in the posterior cingulate cortex

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Objective: Anatomical and neurophysiological evidence suggest a role for posterior cingulate cortex (CGp) in learning associations between stimuli, action, and rewards. CGp is situated at the intersection of brain systems involved in attention, reward processing, and memory, indicated by its connections to parietal cortex, orbitofrontal cortex and anterior cingulate cortex, and the medial temporal lobes, respectively. Moreover, brain imaging studies have repeatedly implicated CGp in both attention and reward processing, and single CGp neurons respond to visual stimulation, shifting attention, and reward delivery. Although there is some evidence that CGp may contribute to learning and memory more specifically, the precise contributions remain unclear.

Methods: We studied the responses of single CGp neurons during associative learning and memory while monkeys performed a variant on the location-scene conditional motor association paradigm. Rhesus macaques learned to associate specific photographs with shifting gaze to a particular target to receive a juice reward (Chen and Wise, 1995; Wirth et al., 2003). Because this task requires information processing in both the orienting and learning systems, as well as reward processing and association, we hypothesized that single neurons in CGp would show learning-related signals. As in previous studies of this form, we included both highly familiar reference scenes and scenes novel for each session. We also varied incentives by providing large rewards for correct responses to some scenes, and small rewards for correct responses to others.

Results: As expected, behavioral performance gradually improved, and was systematically better for high-value scenes. Firing rates of single CGp neurons were also modulated during the task. Specifically, most CGp neurons showed a prominent error signal following the time when the reward would have been delivered. This error signal was larger for new scenes than for previously learned reference scenes, consistent with the idea that it contributes to learning. Finally, a small subset of neurons encoded the expected reward value of the scene in the error signal.

Conclusions: These results suggest that CGp may guide associative learning by linking stimulus to orienting and reward.

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On the Pertinence of Reinforcement Learning for Risk Control

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How well the human brain is adapted to make reward predictions in a changing environment has been a cornerstone of Reinforcement Learning (RL). The standard RL approach is mute, however, as to learning of risk even if it potentially is a hallmark of survival in stochastic and uncertain environments. A sophisticated RL algorithm that uses uncertainty adjusted learning rates for reward learning has recently been proposed (Preuschoff & Bossaerts, 2007).

To investigate how befitting the algorithm is for explaining human risk prediction and risk control, we developed a new experimental paradigm, the Risk Management game. In it, risk changes in line with patterns widely observed in real-world financial markets, and the task is to control risk. Two important properties of the reward generating process are (i) that the evolution of the underlying risk is analytically accessible and (ii) that this evolution can be described intuitively. The latter feature makes it feasible to ask subjects to make actual predictions. An analogy can be drawn to the case of traders making currency quotes absent the knowledge of whether the third party asking for quote will buy or sell the currency at that quote. The optimal strategy is therefore one of risk minimization. On the other hand, it is possible to derive the optimal learning rates from rational expectation based predictions because the conditional distribution of the reward generating process is known.

Results from a sample of 40 subjects indicate that risk and reward learning rates are in line with theoretically optimal ones and that the underlying risk levels modulate risk control in predictable ways. Thus, our results support risk-sensitive learning through the adjustment of learning rates using adaptive coding of reward prediction errors.

Neural Mechanisms of Social Learning and Cognitive Imitation

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Many animals, from honeybees to the great apes, possess the ability to learn from each other, although the mechanisms underlying this learning are not well understood. The two main areas of research into social learning have developed along completely different paths over the last twenty years, with economists focusing on the complex Bayesian updating strategies and perfect memory representations of previous actions whilst animal learning theories suggesting simpler mechanisms may be at work. For social learning to exist it must be adaptive and lead to more efficient reward harvesting (or punishment avoidance) on the part of the observer. Here we present a model that attempts to combine ideas from economic and psychological/ animal social learning theory the using simple algorithms from individual reinforcement learning. Simulations reveal that the model can give rise to social learning similar to that observed in real life. We apply this model to behavioral and fMRI data from a novel social learning task where participants were able to learn from a confederate's outcomes as well as the results of their own decisions. The task consisted of a simple instrumental choice between two fractal stimuli which were associated with different probabilities of reward and punishment. Two levels of social information were available to participants; One where the confederate decisions and outcomes were observable and one where only confederated decisions were shown. Participants performed better with both types of social information compared to individual learning (ANOVA $p<0.001$). We show that 'fictive' or vicarious social teaching signals such as social prediction error are represented in areas previously implicated in 'theory of mind' tasks such as the superior temporal sulcus, and that the vicarious and individual experience of reward and punishment are commonly coded by the ventromedial prefrontal cortex and insula respectively.

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A psychometric-neurometric comparison of subjective value in vmPFC during decision under risk

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Background. A central issue in neuroeconomics concerns the identification of the subjective value computations that the brain needs to perform in order to make choices. Several studies have proposed that such value signals are encoded in the medial or ventromedial prefrontal cortex (vmPFC) for a wide variety of decisions.

The usual approach in these studies is to estimate a psychometric function of subjective value from the choice behavior, and then search for areas in which brain activity correlates with the value signal. An alternative powerful method entails identifying Regions of Interest (ROIs, selected on ex ante grounds) that exhibit a close match between psychometric and neurometric functions (in the former case values are inferred from choice behavior, in the latter it is inferred from neural activity).

Methods. This study utilizes a novel approach to estimate the neurometric functions of decision variables in choice under risk. In order to obtain neurometric measures we asked subjects to participate in two separate tasks: a lottery choice task and a food-bidding task (Plassmann et al. 2007). The food-bidding task was used because (1) previous research has shown that it is effective in eliciting subjective value in vmPFC, and (2) it is independent from the lottery task since it involves neither risk nor monetary outcomes. In the lottery task subjects made choices between pairs of large stake monetary gambles. The set of gambles was chosen so that outcome and probability were fully orthogonalized.

For the neurometric exercise, we defined ROIs in vmPFC using the value related activations from the food-bidding task. Within these ROIs, we then estimated for each subject, neurometric functions of outcome value, probability weight, and subjective value of the lottery. We also estimated psychometric functions of those variables from the choice data.

Results. N=20 subjects participated in the study. Preliminary results suggest that there was a close psychometric-neurometric match in vmPFC. Since the ROIs were selected based on a task independent of the lottery task, this result provides further evidence for a common valuation system in vmPFC that represents subjective value during decision making.

Sleep related changes in attribute recall and choice

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Objective

Conventional wisdom and studies of unconscious processing suggest that "sleeping on it" can benefit decision-making. However, little research has been done on the effects of sleep on the choice process. We investigated how periods of sleep may affect memory for the attributes, or the "pros and cons," of options in a choice set. Furthermore we examined whether "sleeping on it" can affect stability of initial preferences and decision confidence.

Methods

Participants attended two experimental sessions separated by 12 hrs, either spent awake (AM-PM) or containing sleep (PM-AM). During the first session, participants were informed that they would later choose one of four laptop satchels to receive if selected in a random drawing. Participants viewed 36 attribute/brand descriptors (9 per satchel) for 5s each. They then provided liking, desire to purchase, and willingness-to-pay ratings for each satchel. After a ten minute unrelated filler task, immediate recall was assessed and participants were asked to rate the valence of each remembered attribute/brand item. Delayed recall and preference ratings (liking, etc.) were similarly tested 12 hrs later in a second session. At the experiment's close, participants indicated their sleep behavior and made their final choice of satchels.

Results

Sleep showed a significant benefit for recall of attributes; individuals in the PM-AM group remembered more attributes in delayed recall than in initial recall. Conversely, individuals in the AM-PM group showed a significant decrease in performance from initial to delayed recall. In addition, trends in the data indicate that the benefit of sleep may have occurred through increased memory for positive attributes. The decrements in the no-sleep participants' memory showed no reliance on the valence of the information. Notably, despite the memory related benefits of sleep, participants in the PM-AM group were significantly less confident and less satisfied with their final satchel choice.

Conclusions

The results summarized here suggest that while sleep can have significant benefits on memory recall, this information may actually interfere with the decision making process. One possible mechanism is that the additional positive items remembered after sleep may increase the difficulty of discarding options in the choice set. This hypothesis and potential circadian effects are the focus of ongoing research.

A Salesforce-Specific Theory of Mind Scale: Tests of Its Validity by Multitrait-Multimethod Matrix, Confirmatory Factor Analysis, Structural Equation Models, and Functional MRI

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Brain processes of salespeople are investigated in order to discover why some salespeople are better at interpersonal mentalizing than others. Based upon research on autism and neuroscience, we develop a new theory driven scale for measuring salesperson's interpersonal mentalizing skills: which is the ability of salespeople to "read the minds" of customers in the sense of recognizing customer intentionality and processing subtle interpersonal cues, as well as adjusting one's volitions accordingly. The authors refer to the domain-specific theory of mind scale as the salesperson theory of mind (SToM) scale.

The convergent, discriminant, concurrent, predictive, and nomological validities of measures of the scale are established by use of four methods in four separate studies. In Study 1, the authors identify real situations and tasks that require interpersonal mentalizing by actual salespeople, and develop a paper and pencil measure of the SToM. In Study 2, the findings of Study 1 are replicated and the SToM scale is further related to performance and other variables related to interpersonal mentalizing. In both Studies 1 and 2, convergent, discriminant, and criterion-related validities are investigated; Study 2 also goes further to examine nomological validity of the measures of the SToM scale by use of structural equation models. Study 3 then collects data by use of the multitrait-multimethod matrix and uses confirmatory factor analysis to test for the convergent and discriminant validity of measures of interpersonal mentalizing. Finally, in Study 4, in order to identify the brain areas involved in interpersonal mentalizing, and validate measures of the scale at the neural level, functional magnetic resonance imaging (fMRI) and experimental treatments are used to compare salespeople identified as high versus low in interpersonal mentalizing skills, as measured by our scale, and to pinpoint specific differences in neural processing. Results reveal three neural regions in which the activity is greater for salespeople with high compared to low SToM scores; right medial prefrontal cortex (MPFC), and right and left temporo-parietal junctions (TPJ). These regions are part of a distinct network of brain regions that have been shown to activate consistently with mentalizing tasks in prior studies on autism and neuroscience.

So close and so much invested: Goal proximity and sunk effort escalate frustration

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Objective: Frustration aggression theory states that frustration, elicited by the unfulfilled appetitive motivation to attain a reward or goal, is an antecedent to aggression. It has been hypothesized that the amount of frustration is a function of the strength of the desire to obtain the goal. Previous studies suggest that motivation increases with increasing proximity to the goal — the 'goal gradience effect' — and with the amount of prior expenditure in resources or effort, known as the 'sunk cost effect'. Given the hypothesized link between motivation and frustration, we theorized that the closer one is to a goal, and the larger the effort expended on the goal, the stronger the motivation to reach it, and subsequently the stronger the frustration after goal blockage.

Methods: We designed a functional magnetic resonance imaging (fMRI) experiment to assess how reward proximity and expended effort affect the motivation to obtain the reward and the frustration when the reward is blocked. Twenty adult male subjects participated in the study. Following the fMRI session, the subjects rated their motivation and confidence of obtaining the reward at different schedule states and their frustration and surprise after being blocked in those circumstances.

Results: As hypothesized, the self reported motivation to obtain the reward and the frustration after reward blockage were enhanced with increasing reward proximity and effort. Our preliminary fMRI results show that increasing motivation was associated with the activation in ventral striatum and caudate. As the reward blockage occurred closer to the final goal, brain activity in amygdala increased while activity in ventral medial prefrontal cortex decreased.

Conclusions: These results suggest that reward proximity and expended effort modulate the appetitive motivation to obtain the reward and the frustration after goal blockage. We speculate that failure to inhibit the aversive emotion induced by unmet desire may underlie the frustration-evoked aggression.

Medial prefrontal cortex mediates the competitive component of social decision making

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Objective: Neuroimaging studies of human social decision making have emphasised two distinct brain networks underlying social decision making. The first is related to reward and reinforcement learning. These reward-related structures encode complex aspects of reward, such as the amount of regret and social comparison. The second network is implicated in the estimation of another person's intention or mentalizing. Due to the complexity of social interactions, it has been difficult to identify the specific roles of the individual brain regions and how these two networks relate to one another. The goal of this study was to dissect the brain processes involved in social decision making by directly comparing the brain activity underlying "social" and "private" decision making. We also compared the brain networks involved in social and private emotions, after appraising the outcome of a choice in a lottery game.

Methods: We measured brain activity using fMRI while 24 subjects chose between two lotteries. In the private context, they were informed of the outcome of their choice and of the alternative lottery. In the social context, they also observed the choice that another person made as well as the other's outcome. Thus, they had the opportunity to experience regret and envy, or their positive counterparts (relief and gloating).

Results: The striatum, a brain structure implicated in reward processing, encoded both relative gains and losses, and the different gambling contexts. It showed amplified responses for gloating and envy events in the social context, compared with private events (regret and relief).
The medial prefrontal cortex (mPFC) was more activated for gloating events than for all other events. That is, the mPFC signaled events for which the individual performed better than their counterpart. Since this region was not activated when the two players made the same choice, it does not simply encode the social vs. private context but rather a competitive component of the social interaction. A connectivity analysis revealed that the same mPFC region was reactivated during choices with amplified activations for social choices in comparison to private choices. Moreover, subjects whose mPFC was activated more during choice in the social condition were those in whom the striatum was activated more during outcome evaluation for gloating events.

Conclusions: Thus, the mPFC responds to situations associated with maximal pleasure triggered by gloating events. Presumably, the mPFC leaves a trace of experiencing gloating events in a large network, and reactivates this trace during subsequent choices, in order to bias decisions in a way that will maximize gloating.

The Influence of Communication on Non-Interpersonal Trust: The Case of eBay

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Objective: Because of uncertainty and asymmetric information, trust is a fundamental precondition for successful interpersonal interactions in modern societies, in particular in economic exchange. However, little is known about trust in post-modern non-interpersonal interactions. In particular, in online environments, where the interpersonal link is often nonexistent, the neuronal mechanisms for the development of trust, to our best knowledge, have not yet been studied. However, an important driver for non-interpersonal trust in online environments could be communication (e.g., in eBay transactions). Therefore, we analyzed if (a) a certain communication theory (i.e., Toulmin's theory of argumentation) can be applied to evoke trust in online settings and (b) the neural mechanism of non-interpersonal trust are similar to the mechanism in situations of interpersonal trust.

Methods: We used Toulmin's theory of argumentation to modulate Internet offers (eBay offers of new USB-flash drives) with a varying degree of conclusive argumentation. First, 104 eBay offers were pretested and split into three groups (high, neutral, low) regarding their trustworthiness level. Then, we selected the ten most and ten least trustworthy offers as well as ten neutral offers for the imaging study. Ten male and ten female subjects participated in the fMRI session. Participants had to evaluate the trustworthiness of the eBay offers projected into their visual field. Statistical analyses were conducted with SPM5. Three regressors contained the image time for each trustworthiness level (high, neutral, low). For the group analysis, the contrast images for the conditions high trustworthy versus low trustworthy eBay offers were analyzed with a one sample t-test using the contrasts of the single subject analysis.

Results: First, we found that communication on the basis of Toulmin's theory can evoke—with few exceptions—trust in online environments. Second, by contrasting high and low trustworthy offers ($p<.0001$ (uncorr.)), we observed significant activity changes within the lingual cortex, the dorsal posterior and anterior cingulate cortex as well as the striatum. Conversely, by contrasting low and high trustworthy offers ($p<.001$ (uncorr.)), we observed significant activity changes within the ventromedial prefrontal cortex, the ventral posterior and anterior cingulate cortex, and the insula.

Conclusion: The present study shows that (a) Toulmin's theory can, with few but notable exceptions, be applied to evoke trust in online environments and (b) changes in brain activity in non-interpersonal trust situations resemble the changes in interpersonal trust situations.

Shared neural substrates for social and non-social reward processing

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Objective: A large body of work has shown that the ventro-medial prefrontal cortex (vmPFC) and the ventral striatum (VtStr) both participate in decision-making: the vmPFC encodes the values of different options at the time of choice and the VtStr encodes a prediction-error feedback signal that can be used to learn the value of stimuli. Although these findings have been replicated in multiple species, and with various techniques and protocols, most of the existing data uses non-social rewards. An open question is whether social and non-social rewards are processed by identical circuitry, or whether social rewards feature some domain-specificity.

Methods: We addressed this fundamental question with a novel functional Magnetic Resonance Imaging (fMRI) study. The key feature of the experiment was that subjects played two versions of an otherwise identical version of the task, one with social rewards and a second with non-social rewards. In both versions, subjects chose between two bandits characterized by different stochastic distributions of positive, neutral, or negative outcomes. In a monetary condition, rewards were winnings of +\$1, \$0, or -\$1 while in a social condition, rewards were smiling, neutral, or angry faces accompanied by socially charged sounds. Ratings obtained from the participants verified that both monetary and social stimuli spanned a parametric range from negatively to positively rewarding.

Results: We found that subjects learned to choose the bandits with the highest expected value equally well in the non-social and social conditions, which confirmed behaviorally the rewarding nature of the social stimuli. Furthermore, constructing value estimates at each time point from subject choices to probe regional BOLD activation, we found that overlapping areas of the vmPFC encoded the value of the bandits at the time of choice in both conditions, and that overlapping areas of the VtStr encoded reward prediction errors at the time the stochastic outcome was revealed.

Conclusions: These results provide preliminary support for the existence of a common set of decision making processes that are engaged by both social and non-social reward.

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Propensity for selfish behavior in the dictator game is affected by frame-order parsing

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Objective: Evidence from response time, imaging, and TMS studies suggests the existence of a multi-part mechanism that controls behavior in laboratory altruism games. In particular, there appears to be a mechanism for implementing social preferences in place of the preferences one would expect from entirely self-regarding *Homo economicus*. This experiment provides additional evidence for this model of social preferences.

Methods: Roughly four hundred subjects participated in the experiment. Subjects were evenly split between four modified dictator games: two baseline games in which rights over the initial allocation were inverted, and two treatment games in which initial allocations were symmetric, but the frame-order parsing was inverted. The experiment was also novel in that data were collected using a secure online system in which the subjects played for entries into a point-weighted cash-equivalent lottery, rather than directly for a previously specified amount of money.

Results: The data from the baseline treatments followed the pattern of previous experiments with modified dictator games. Subjects behaved with fuzzy expectations over small stakes in this study as they do with the average laboratory payments, as evidenced by the pattern of dictator transfers. Altering initial allocations had an effect on the magnitude of transfers that was driven by a change in the magnitude of transfers by altruistic subjects. The fraction of selfish players in the differential allocation treatments was constant. As expected, changing the order of frame parsing in the symmetric games had a significant effect on transfers as well. However, the effect was driven by a change in the proportion of players behaving selfishly, while the difference in magnitude of transfers by altruists was statistically insignificant.

Conclusions: These results provide further evidence for a multi-part mechanism model of altruism. Under certain treatments, altruistic behavior can be influenced by changing altruistic preferences, while in other circumstances behavior is influenced by changing the propensity of people to behave altruistically at all. Furthermore, we confirm for small fuzzy stakes the result previously observed by Fehr, Fischbacher and Tougareva for very large stakes that behavior in the dictator game does not appear to depend significantly on the size of the pot.

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Social Decision-Making in the Elderly

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Objective: Recent evidence suggests the neural circuitry underlying decision-making differs depending upon the domain (e.g. social vs. purely economic) in which that decision is made. We tested the hypothesis that increased age differentially affects decision-making in social games, such that the elderly show a reduction in the efficiency. Our goal is to characterize decision-making in young and elderly participants in the social domain and determine the underlying neurobiological processes of age-related behavioral preferences. Aging results in functional (e.g. increased PFC activity) and anatomical (i.e. atrophy) changes in the brain, thus these vulnerabilities may inform us about the neural circuitry of decision-making.

Methods: Young (age: 25-45) and old (age: 65-85) subjects participated in the study. Participants made a series of choices for real monetary gains in social decision-making tasks. Social decision-making was assessed using through self-report (DOSPERT) and behavioral testing including the Ultimatum Game (UG), Dictator Game (DG) and Trust Game (TG).

Results: The elderly reported that they were less likely than the young to engage in behaviors that include social risk as measured by the DOSPERT ($p<.01$). This is true even though the two groups perceive similar amounts of risk in these types of situations. The old accept fewer low, unfair, offers in the Ultimatum Game ($p<.001$) than the young. Interestingly, the elderly will often forgo reward entirely rather than accept an unfair offer. The elderly are also more likely to evenly share a sum of money in the Dictator Game ($p<.001$) as compared to the young. Finally, the old are more conservative when investing sums of money in the Trust Game ($p=.08$).

Conclusions: These results suggest age affects decisions made within a social framework. The mechanism underlying age-related differences in decision-making are still to be empirically investigated. Our data are consistent with previous literature suggesting that social decisions require regions of the brain that assess the emotional aspects of a decision and the reflection on the state of mind of others. These processes are often attributed to cortical regions such as the insula and prefrontal cortex that are affected by aging. Armed with this behavioral data our on-going neuroimaging study will focus on distinguishing the neural systems involved in social judgments from those involved in assessing risk. Preliminary neuroimaging data will be included.

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Mechanisms of Social and Non-social Framing Effects

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Objective: Context can frequently bias decision making. For example, a person might be more likely to consider undergoing an operation when the surgeon frames the potential outcome as 90% chance of survival as opposed to 10% chance of death—even though these options represent exactly the same outcome. Neuroimaging studies focusing on individuals' choices in these types of scenarios have demonstrated that this so-called "framing effect" is mediated by activation of the amygdala and dorsomedial prefrontal cortex. Yet, it is unclear whether these results extend to contexts where individuals choose for a greater good (e.g., a charity) rather than themselves.

Methods: We used fMRI to measure brain activation while participants (n = 64) engaged in a financial decision-making task that has been previously used to study framing. On each trial, participants were shown a starting amount ($10, $20, $30, $40) before choosing between "sure" and "gamble" options. The sure option was framed such that the participant could keep (gain frame) or lose (loss frame) a fixed proportion of the starting amount. The gamble option did not differ according to frame and was represented by a pie chart reflecting the probability (25%, 50%, 75%) of winning or losing the entire starting amount. On half the trials, participants played for themselves, and on the other half of the trials, they played for a charity of their choice. We also collected saliva samples for later candidate gene analyses.

Results: We observed increased gambling in loss frames ($M = 46\%$) compared to gain frames ($M = 28\%$), suggesting a robust framing effect. Strikingly, participants also exhibited greater susceptibility to the framing manipulation when playing for their chosen charity ($t_{(63)} = 2.8$, $p < .01$). Neuroimaging revealed increased activation in ventromedial prefrontal cortex for decisions involving charity relative to self. The reverse contrast (self > charity) revealed increased activation in dorsolateral prefrontal cortex and parietal cortex.

Conclusions: Our results demonstrate that susceptibility to the framing effect is greater when individuals play for a charity compared to when they play for themselves. This behavioral effect could be explained by neural differences between self and charity trials that are present independent of choice. Future work in this area should explore specific genetic markers that explain individual differences in framing effect between social and non-social contexts. One potential candidate gene would be CNR1, which has previously been associated with modulating social reward processing in the ventral striatum.

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Trust games – are effort and money equivalent?

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Objective: The interplay of the utility of potential rewards and the disutility of spending effort characterizes many of our everyday decisions. Trust games are typically phrased in terms of monetary rewards and losses and very little is known about trust in the context of effort. This is an important gap, since in a typical labor relation the worker invests effort. As trust games are frequently used as models of labor relations it is important to insure that the results generalize to effort. Trusting of effort is commonplace in our society, for example, friends often help one another move. Here we wanted to ask if framing a trust game in terms of effort leads to the same trust and reciprocity levels as framing it in terms of money.

Methods: In this study, each subject performed both a monetary and a "physical effort" version of a trust game experiment. The monetary version was a standard trust game where the investor decides how much money to give to the trustee, the amount of which was tripled. The trustee then decides how much money to reciprocate. In the effort version, subjects had to perform work (mechanical energy) in the form of squats, which was measured using force sensors. The effort game was analogous to the monetary version, except that subjects had to perform a predetermined amount of work. The investor could work for the trustee and any effort was tripled. Subsequently the trustee could reciprocate work to the investor. We analyzed the inter-individual and intra-individual differences between both versions in both investment and reciprocity.

Results: Following our observation that colleagues of ours seem to be more willing to work for one another than to give each other monetary presents, we assumed that subjects would invest more in the context of effort. Indeed we found that people tend to invest more when the trading quantized units of energy and not dollars ($p<0.05$). We also found a significant correlation ($r=.74$, $p<0.05$) between subjects' investment of money and effort.

Conclusions: We found that subjects trust one another more when effort is involved in the transaction than when money is involved. This mirrors our observation in real life and may be related to the difference in context between our effort interactions that are typically with well-known employers or friends, and our monetary interactions that are often with commercial agents. The strong correlations that we found between trusting in monetary situations and in effort situations imply that monetary trust games can indeed be used to estimate subjects' willingness to trust effort to one another. This validates the usefulness of monetary trust games as models of labor interactions. These strong correlations may also indicate shared neural resources between the two tasks.

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Neural reactions to inequity

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Objective: A widely accepted social norm holds that equal work performance should lead to equal pay-off (the equity principle). When the equity principle is violated, however, the subjective experience typically differs greatly, depending on whether the violation is to one's advantage or to one's disadvantage. Both empirical findings and theoretical considerations suggest differences in how people treat situations of disadvantageous (DI) and advantageous inequity (AI). First, dissatisfaction is on average higher for DI than for AI, evidenced by the fact that rejection of DI appears to be much stronger and invariably present across subjects than rejection of AI. Accordingly, outcome-oriented models of social preferences assume that the discount of utility is greater with DI than with AI. On a neural level, relative differences in income affect activity in the ventral striatum (VS). It has been proposed that VS activity reflects preferences in general, i.e. activity is higher in preferred than in less preferred situations. If different motives (such as self-interest and fairness norms) are in conflict, VS activity appears to represent the net preference after an evaluation process based on other brain regions such as the anterior insula, amygdala and prefrontal regions. Based on our previous findings showing that activity in the VS increases with higher relative rewards, we now investigated differences in processing DI and AI.

Methods: Using functional magnetic resonance imaging in 64 subjects we measured hemodynamic brain responses to monetary rewards in subjects who simultaneously observed the reward of another subject in an adjacent scanner.

Results: When subjects observed the other subject receiving a higher reward than themselves despite the same performance (i.e. were in a position of DI), we found strong activation of dorsolateral and medial prefrontal regions and a deactivation of the reward processing ventral striatum. Self-reported aversion to DI was strongly correlated with amygdala activity in the DI condition. AI, on the other hand, elicited only weak activation in prefrontal areas and was not associated with reward-related brain activity. Self-reported aversion to AI was strongly correlated with right VLPFC activity

Conclusions: . Our study highlights the importance of both subcortical, reward-related brain regions and the prefrontal cortex in the evaluation of social inequity. We suggest that the evaluation of DI and AI is guided by different brain structures. Further studies will have to elucidate the interplay between the structures and widen the scope to different aspects of social preferences and how they are integrated into decisions.

Saturday, September 26, 2009
Abstracts for Session 3

Value Systems

10:25 – 10:45 am	Cendri Hutcherson	Parallel reinforcement learning signals in the hippocampus and striatum guide acquisition of stimulus-outcome and stimulus-reward associations	Cendri A. Hutcherson & Antonio Rangel
10:50 – 11:10 am	Mathias Pessiglione	Hemispheric dissociation of the human brain valuation system	Mathias Pessiglione, Stefano Palminteri, Liane Schmidt & Gilles Lafargue
11:15 – 11:35 am	Jan Peters	Complementary valuation systems in the human brain	J. Peters & C. Büchel.

Parallel reinforcement learning signals in the hippocampus and striatum guide acquisition of stimulus-outcome and stimulus-reward associations

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Goal-directed decision-making depends on the ability to learn from experience to correctly forecast the outcomes generated by different choices. How the brain learns to make these predictions is poorly understood, but a growing body of research suggests the involvement of two separate mechanisms: (1) a system that predicts reward using direct stimulus-*reward* associations, and (2) a system that predicts reward indirectly by first computing stimulus-*outcome* associations, and then evaluating options by evaluating the reward value of the predicted identity. Reinforcement learning, in which prediction errors are used to update future predictions, has proven highly successful in capturing features of stimulus-reward learning, including neural responses in the midbrain and ventral striatum. Whether stimulus-identity learning is accomplished by similar or different mechanisms in the same or different brain regions is not yet clear.

To examine this question, we used a novel Pavlovian learning task in which different cues predicted multiple distinct reinforcers of equivalent or varying reward value. The design of the task allowed us to construct structurally similar but independent reinforcement learning algorithms for both reward and identity prediction errors during each trial. This task revealed a striking separation between the correlates of reward prediction errors in the ventral striatum, and correlates of identity prediction errors in the hippocampus. Within the medial and orbitofrontal cortices, we observed overlapping signals independently related to value and identity. These results support a model in which value and identity learning signals are computed in parallel within subcortical circuits, and then integrated to generate predictions in frontal regions important for goal-based value computation.

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Hemispheric dissociation of the human brain valuation system

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Objective: In economics, decision-making consists in weighing the expected values of potential alternatives and selecting the optimal action that is to be executed by slave effectors. Little is known however about how action values are represented in the human brain: are they integrated into a single center or distributed over different areas? Our working hypothesis is that action values are topographically represented in relation to sensorimotor somatotopy. As a first step we aimed here to dissociate values of actions that would specifically engage either the left or right hemisphere.

Methods: We presented visual cues on the left and right of a central fixation cross, and ask subjects to respond with either their left or right hand. In a first neuroimaging experiment, the cues were abstract symbols associated with monetary rewards through probabilistic contingencies that subjects had to learn so as to maximize payoff. Learning curves were fitted with a standard computational model that updates the value of the chosen action in proportion to a reward prediction error. We then searched for brain regions specifically reflecting option values when subjects have to make their choice. In a second behavioral experiment, the cues were coin images that were sometimes masked such that subjects could not perceive them consciously. They had a power grip in either the left or right hand and had to produce as much force as possible in order to maximize payoff.

Results: The first experiment revealed that the values of left and right actions, whether they were chosen or not, were specifically expressed in the controlateral ventral prefrontal cortex. In contrast, the action to be executed, regardless of its value, was represented in the contralateral motor cortex. The second experiment showed that subliminal monetary incentives modulate force production only when they were targeted to the brain hemisphere contralateral to the hand squeezing the power grip. On the contrary, when coins were consciously perceived, higher incentives elicited more grip force whatever the hand used.

Conclusions: Brain hemispheres appeared to specifically track the values of actions under their respective control. In situations where the information is not shared between hemispheres, each may pursue its own expected value. This may happen not only with subliminal stimulations but also in split-brain patients who exhibit the so-called anarchic hand sign.

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Complementary Valuation Systems in the Human Brain

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Objective: The value of different types of rewards may be represented in partially distinct neural systems, but efficient choice behavior requires a common neural coding of stimulus value. We addressed this issue by comparing the neural systems tracking the subjective value of delayed and probabilistic real monetary rewards.

Methods: Twenty-two healthy young volunteers made repeated choices between 20€ available immediately and larger amounts available after some delay (delay discounting) or with reduced probability (probability discounting) while fMRI data were acquired using a 3T MRI scanner (Siemens Trio). Behavioral data were modeled using hyperbolic discount functions and subject-specific model-based estimates of value were used as parametric regressors the in analysis of the MRI data.

Results: A conjunction analysis revealed that ventral striatum and orbitofrontal cortex activity scaled with the subjective value of both delayed and probabilistic monetary rewards. Delay-specific value coding was observed in frontal pole, posterior cingulate and lateral parietal cortex, whereas probability-specific value coding was observed in superior parietal cortex and middle occipital gyrus.

Conclusions: A core system consisting of ventral striatum and orbitofrontal cortex coded for subjective value in a domain-general manner. Regions previously implicated in episodic future thinking, on the other hand, were better correlated with subjective value of delayed than probabilistic rewards. A network of parietal regions previously implicated in the processing of magnitudes and numerical information was more involved in value-coding for probabilistic rewards. Our data thus suggest that both domain-specific and domain-general mechanisms underlie subjective stimulus valuation.

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Poster Session II: Saturday 1:00 – 3:00 pm

#	Title	Authors
1	Net Emotional Response Strength and fMRI: Preliminary Results	M. Hubert *, M. Hubert , F. Hansen , A. Bechara , and P. Kenning
2	I love Shopping? Neural Antecedents of Compulsive Buying	M. Hubert, M. Hubert, T. Eberhardt, and P. Kenning
3	Expectation of Wage Offer Inherits the Properties of Prospect Theory Value Function: Behavioral Evidence from fMRI Study	J. Suomala, V. Leppihalme, J. Heinonen, and J. Numminen
4	The decimal effect: nucleus accumbens activity correlates with within-subject increases in delay discounting rates	Kacey A. Ballard, Sébastien Houde, Shayla Silver-Balbus, Samuel M. McClure
5	Probability discounting of brain stimulation reward	Y.-A. Breton, K. Conover & P. Shizgal
6	Don't Stop Thinking About Tomorrow: Neural Measures of Future Self-Continuity Predict Temporal Discounting	Hal Ersner-Hershfield, G. Elliott Wimmer, Brian Knutson
7	The value of work: Role of dopamine in effort discounting	Suzanne H. Mitchell
8	Executive Control of Intertemporal Choice: Effects of Cognitive Load on Impulsive Decision-Making	Sarah J. Getz, Damon Tomlin, Leigh E. Nystrom, Jonathan D. Cohen, Andrew R. A. Conway
9	Cuing of post-reward delays substantially reduces impulsivity in macaques in an inter-temporal choice task	J. Pearson, B.Y. Hayden, and M.L. Platt.
10	Single frontal neurons encode probabilistic reward prediction errors	S.W. Kennerley and J.D. Wallis
11	Role of orbitofrontal cortex in confidence judgments in rats	G.M. Costa, A. Lak, Z.F. Mainen, A. Kepecs
12	Value-based gain control: a model of context-dependent choice	Kenway Louie and Paul Glimcher
13	Dissociable Neural Signals for Valuation and Salience at the Time of Decision Making	Ab Litt, Hilke Plassmann, Baba Shiv and Antonio Rangel
14	A Bayesian account of the role of attention in value-based decision-making.	D. Ray and A. Rangel
15	The Relative Role of Visual Saliency and Value in Rapid Saccadic Choice	Milica Milosavljevic, Vidhya Navalpakkam, Christof Koch, & Antonio Rangel
16	Cognitive modulation of goal values at the time of decision making	Cendri Hutcherson, Hilke Plassmann, James Gross, Antonio Rangel
17	Retrospective Evaluations in Capuchin Monkeys: The evolution of end-point sensitivity	Venkat R. Lakshminarayanan, Webb C. Phillips, and Laurie R. Santos
18	Personal, generic and automatic: three core features of the brain valuation system	Maël Lebreton, Soledad Jorge, Vincent Michel, Bertrand Thirion and Mathias Pessiglione
19	Valuation in a Sequential Choice Task Utilizes Dorsomedial Prefrontal Cortex	C. Luk, and J.D. Wallis
20	Supplementary eye field reflects both value and direction of the saccadic choice in a gambling task	Veit Stuphorn, Na Young So
21	Dynamical Bayesian computations of decision values in vmPFC	Shih-Wei Wu, Shinsuke Shimojo, John O'Doherty, Antonio Rangel
22	Asymmetric BOLD responses to positive and negative outcomes	Robb B. Rutledge, Paul W. Glimcher
23	Seeking rewards and avoiding punishments over the adult life span	G.R. Samanez-Larkin, L.L. Carstensen, and B. Knutson
24	The Contingency of Gain and Loss Influences Decision Making in a Modified IGT	Nai-Shing Yen, Chang-Hao Kao, I-Chen Chou, Hsuan-Yu Lin, Hui-Kuan Chung, Kuan-Hua Chen
25	The Neuroeconomics of Money	Donald Wargo
26	Why hire a broker? Neuroeconomic factors and financial decision making	John M.R. Chalmers, William T. Harbaugh, Ulrich Mayr, Benjamin Bushong, Eric Duquette
27	Using a computational phenotype to investigate the genetic basis of decision-making under risk	Cary Frydman, Colin Camerer, Peter Bossaerts, Antonio Rangel
28	Individual and genetic differences in risk preference and loss aversion	O.A. Mullette-Gillman, K.M. Schiabor, E.T. Cirulli A.G. Robinson, J.R. Meyer, D.B. Goldstein, M.L. Platt, J.H.P. Skene, and S.A. Huettel
29	Which neural reactions do negative payoffs cause in risky decision making?	Marcus Heldmann, Ralf Morgenstern, Thomas Münte, Bahram Mohammadi, Bodo Vogt

30	Is brain activity observable that leads to an evaluation of a probability of 0.5 that is different from 0.5 in binary lottery choices?	Marcus Heldmann, Ralf Morgenstern, Thomas Münte, and Bodo Vogt
31	Measuring Strategic Uncertainty and Risk in Coordination-, Entry-Games, and Lotteries: an fMRI study	Andrea Brovelli, Frank Heinemann, Rosemarie Nagel and Giorgio Coricelli
32	Coding of risk and expected value by distinct neurons in the orbitofrontal cortex	M. O'Neill and W. Schultz.
33	Neurometric Predictors of Risky Decision Making in Children	David Paulsen, McKell Carter, Scott Huettel, Michael Platt, Elizabeth Brannon
34	Will Gamble for Food: Risk Sensitivity with Pigeons in a Token-Reinforcement Paradigm	Carla H. Lagorio and Timothy D. Hackenberg
35	Learning to avoid financial losses: a critical role for the insula.	Stefano Palminteri, Virginie Czernecki, Carine Karachi, Laurent Capelle and Mathias Pessiglione

Net Emotional Response Strength and fMRI: Preliminary Results

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Objective: The application of traditional measurement instruments to analyze emotional responses towards brands often seems to be insufficient to capture intangible and unconscious aspects within the consumer decision-making process. On the other hand neurological studies emphasize the importance of essential emotional processes underlying human decision-making. Therefore, the focus of this preliminary study is to link a questionnaire based measurement technology (Net Emotional Response Strength (NERS)) with an fMRI-experiment in order to firstly, shed light on the functionality and the validity of the traditional measurement instrument and secondly, to interpret results of the behavioural level in the light of neurophysiologic insights into emotional processing.

Methods: Nine male and nine female subjects participated in the study. Within the fMRI experiment, all participants had to evaluate 35 different brand logos twice according to their attractiveness. Additionally, we applied a modified version of the original NERS-Measurement for each brand after the fMRI. 10 out of 24 feeling-brand association-items (6 positive, 4 negative) had to be evaluated on a 5 point Likert scale. The individual NERS-Score included on the one hand the multiplication of a general factor loading with the individual rating for each association-item and on the other hand, the differential of the positive-item-sum and the negative-item sum. Three brands (BOSS, Calvin Klein, and Giorgio Armani) were analyzed within a first preliminary investigation. For the fMRI-analysis, we defined two groups on the basis of a mean split: group (high NERS-Score (HNS)) with participants scored above the brand mean and group (low NERS-Scores (LNS)) with participants scored below the brand mean. Three onsets were built in order to contrast group (HNS) with group (LNS) for each brand.

Results: An ANOVA confirmed all groups to be significant different ($p<0.001$) defined by the mean split for each brand (M(Boss) = 7.48, M(GA) = 6.31, M(CK) = 8.29). The fMRI analysis revealed the following selected results: By contrasting HNS versus LNS ($p <.005$ (unc.), $k>10$) we obtained significant changes in activity that included a neural circuitry consisting of the ventromedial prefrontal cortex (BOSS, GA), the posterior cingulate gyrus, and adjacent precuneus (BOSS, CK),the dorsal striatum (BOSS) and ventral striatum (CK) the, ,and the caudate nucleus (CK). Vice versa by contrasting LNS versus HNS ($p<.005$ (unc.), $k>10$) we observed significant activity changes within the ventromedial prefrontal cortex and the insula (BOSS).

Conclusion: By applying NERS-scores for grouping the participants we observed significant activity changes within brain regions associated with reward, emotions and memory processing. Although the revealed results are very preliminary, first insights for linking traditional measurements of emotional responses to brands and fMRI could be provided. Nevertheless further research is needed to develop and validate our results.

I love Shopping? Neural Antecedents of Compulsive Buying

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Objective: Compulsive buying (CB) is defined as chronic, repetitive purchasing that becomes a primary response to negative events or feelings. CB is a prevalent, but often trivialized problem of western societies and in contrast to normal impulse purchasing that is fulminating and often focused on a certain product, CB is a chronic state featured by the longing to buy. An important characteristic of CB is that consumers report euphorically emotions during the buying process itself, whereas the possession of the product is only secondarily. Therefore we hypothesize that consumers who are prone to CB show primarily activity changes in regions that are associated with reward and emotions in contrast to consumers who are not when evaluating attractive brands.

Methods: Ten male and ten female subjects participated in the study. During the fMRI session, a logo of a pretested brand was projected into the visual field of the participants. In a forced-choice-task, participants had to evaluate each of the selected brands twice according to their attractiveness. A questionnaire, including the German Addictive Buying Score, was used to split male and female participants into two different groups (prone/not prone to CB). Statistical analyses were conducted with SPM5. Two regressors (attractive/unattractive) contained the individual decisions of each participant. The regressor (attractive) was used for a two sample t-test between both defined groups (prone/not prone to CB).

Results: The contrasting of both groups (separately for men and women ($p<.001$ (uncorr.)) revealed significant activity changes in the caudate nucleus and the anterior cingulate gyrus. The male participants showed additionally activity changes in the putamen, the thalamus, the amygdala and the medial frontal gyrus. Therefore, the analysis of our data and the identified structures confirmed our hypothesis. Participants who are prone to develop CB showed activity changes in brain regions that are associated with reward and emotion in contrast to participants who are not when evaluating attractive brands.

Conclusions: Our study provides first insights about the neural mechanisms underlying CB. First, consumer with proneness to CB show stronger activity changes in regions associated with the "reward system" and emotions by evaluating attractive brands. Second, regarding the discussion if CB can be ascribed to addiction or obsessive compulsive disorders our data showed in combination with previous studies that there might be not only symptomatically but also neural semblances to both categories.

Expectation of Wage Offer Inherits the Properties of Prospect Theory Value Function: Behavioral Evidence from fMRI Study

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Objective: Despite 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 during economic search has been explained without PT. On the contrary, choice behavior in economic search literature has been explained by search cost, presence or absence of recall (Schotter & Braunstein 1981), the role of minimum wages (Falk, Fehr & Zehnder, 2005), and the variation in the amount of a fixed payment (Abeler, Falk, Götte & Huffman, 2009). In order to study the role of a subjective RP in economic search, we constructed a testable economic search model to represent the elements present in a subjective choice situation.

Methods: A novel ROA (Reject Or Accept) experiment suitable for fMRI studies has been constructed. In ROA, the subjects (n=25) evaluate a set of salary offers by rejecting or accepting the offer. Before the fMRI scan, the subjects answer a question on their personal salary goals after graduation. The content of the offers vary depending on the participants' subjective RP. However, the range of offers will be the same. During the fMRI scan, 50 sets of salary offers are presented, one at a time, for the participants to judge between "accept" and "reject". The number of offers in every set range from 1 to 5 and the content of offer is based on a uniform distribution in which salary offers range from -30% to +60% of the RP.

Results: The behavioral data has been analyzed. A personal valuation function has been counted for each subject. The study shows that the value function collected from economic search data inherits the properties of PT. First, the reference point divides the offers into regions of gain and loss. Second, during economic search, outcomes that are encoded as losses are more painful than gains of equal amount are pleasurable $[v(x) < |v(-x)|, x>0]$, e.g. $[v(+10RP)>|v(-10RP)|]$. Further, the results show that outcomes have a smaller marginal impact when they are more distant from RP.

Conclusions: The study shows that during economic search the valuation of wage offers follows the features of the PT (Kahneman & Tversky 1979). To the best of our knowledge, this is the first time when choice behavior during economic search can be explained by PT. In near future, we may find out how brain activity correlates to the PT value function.

The decimal effect: nucleus accumbens activity correlates with within-subject increases in delay discounting rates

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Dual-system models of delay discounting hypothesize that discount rates depend on separate cognitive and automatic valuation processes (Hariri et al., 2006; Hinson et al., 2003; McClure et al., 2004, 2007; Shamosh et al., 2007; Thaler and Shefrin, 1981). According to these models, one parameter that governs discounting is the automaticity of the evaluations. In particular, brain regions associated with the mesolimbic dopamine system are believed to signal reward due to direct associative learning. Greater experience with a dimension of reward is therefore predicted to (i) recruit dopamine-related brain areas more effectively, and (ii) bias delay discounting in favor of more myopic, automatic assessments.

We demonstrate this relationship here with what we call the decimal effect. Our experiment begins with the hypothesis that round numbers (e.g. \$10.00) are more familiar and hence are processed differently than are non-integers (e.g. \$10.72). We demonstrate this decimal effect behaviorally by showing that people are both faster ($p<0.05$) and more accurate ($p<0.01$) at making magnitude judgments involving round numbers than non-integers (comparisons against non-integers in all cases).

In a delay discounting task, we show behaviorally that discount rates are higher for choices involving round numbers than for choices involving non-integers ($p<0.05$). Using functional MRI, we show that activation in the nucleus accumbens is greater for choices involving round numbers than for non-integer choices. Furthermore, the degree of the difference observed in the nucleus accumbens correlates with individuals' shift in discounting rates.

Finally, since we found that round numbers are easier to evaluate and recruit greater mesolimbic dopamine activity, we hypothesized that intertemporal choice behavior could be biased in *either* direction by selectively using integers on only one of the options. We found discounting rates significantly increased when only the immediate amount was a round number ($p<0.05$); however, discounting rates significantly decreased when only the delayed amount was a round number ($p<0.05$).

These findings have significant implications for drug addiction and other mental health problems that are associated with abnormal discounting behavior. By subtly altering aspects of an intertemporal choice it is therefore possible to change decisions in a manner that may benefit long-term health outcomes.

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Probability discounting of brain stimulation reward

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Objective: The rewarding effect of electrical brain stimulation provides a convenient means of studying the neural basis of decision making in laboratory animals. We have developed a 3D model relating performance to the strength and cost of reward. Stimulation pulses trigger a volley of action potentials in the axons that give rise to the rewarding effect; the post-synaptic effects of the volley are subsequently integrated, and the peak activation is recorded as an engram. Based on the scalar combination of subjective costs with this stored record of subjective reward intensity, the rat allocates its time between operant performance and competing activities, such as resting and grooming. This model can distinguish between alterations in processing that occur prior to the output of the integrator from those occurring at or beyond this stage of processing. We have shown previously that the effects of a manipulation acting prior to the output of the integrator confirm the predictions of the 3D model. The present experiment tests predictions concerning processing beyond the integrator output.

Methods: Rats worked for electrical stimulation of the medial forebrain bundle that was delivered once they had held down a lever for a required cumulative time (the "price" of the reward). One lever delivered the reward on every occasion that the hold-time criterion was met (riskless lever), and a second lever paid off at a probability of either 0.75 or 0.5 (risky lever); only a single lever was available on a given trial.

Results: A rat working for risky rewards delivered with a probability of 0.5 will have to hold down the lever, on average, twice as long as when a riskless reward is delivered with a probability of 1.00. Thus, changing reward probability should alter performance along an axis representing the price of the reward. In contrast, the function mapping stimulation strength into subjective reward intensity should be unaltered. With only minor exceptions, risky options reduced rats' propensity to work for a given level of reward without altering the mapping of stimulation strength into subjective reward intensity.

Conclusions: The results support a key proposition of the 3D model: that the intensity and cost of reward are independently represented and computed. As predicted, the subjective probability of reward enters into the computation of payoff at a stage of processing downstream from the spatiotemporal integration of the electrically induced reward signal. The methods employed provide a quantitative description of probability discounting in the rat.

Don't Stop Thinking About Tomorrow:
Neural Measures of Future Self-Continuity Predict Temporal Discounting

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<u>Objective:</u> We tested the future self-continuity hypothesis that individuals perceive and treat the future self differently from the present self, and so might fail to save for the future. To examine this hypothesis, we used behavioral measures that relied on self-report, as well as neuroimaging measures that did not. Neuroimaging offers a novel means of testing this hypothesis, since previous research indicates that self- versus other-judgments elicit activation in the rostral anterior cingulate (rACC). Using event-related functional magnetic resonance imaging (fMRI), we predicted that there would be individual differences in rACC activation while rating the current versus future self, and that individual differences in current versus future self activation would predict temporal discounting assessed behaviorally a week after scanning.

<u>Methods:</u> In Study 1, 155 community members filled out a novel future self-continuity scale, as well as a comprehensive financial history questionnaire. In Study 2, 18 subjects were scanned with event-related fMRI while making judgments about the extent to which trait adjectives applied to their current self, a future self, a current other, or a future other. A week later, subjects completed a temporal discounting task that yielded an estimate of the degree to which each individual discounted future rewards. Analyses focused on changes in activation in the MPFC and rACC during current vs. future self-ratings.

<u>Results:</u> In Study 1, there was a significant positive correlation between our measure of self-continuity and accrued assets. In Study 2, results indicated that there was a neural difference between thoughts about the current self versus thoughts about the future self: there was greater activation in a portion of the anterior cingulate cortex for current self compared to future self judgments. Importantly, lending further support to the future self-continuity hypothesis, individual differences in the magnitude of this effect predicted the tendency to devalue future rewards. That is, the greater the difference in neural activation between current self and future self judgments, the more a given individual discounted future rewards.

<u>Conclusions:</u> These results suggest that the way one views the future self is an important predictor of saving behavior. Such a relationship was documented using both behavioral and neuroimaging methods. The findings thus may hold implications for understanding and encouraging saving for the future self.

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The value of work: Role of dopamine in effort discounting

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Objective: Most studies manipulating the effort required to earn a reinforcer do so by altering the number of responses required to earn rewards. This establishes a strong correlation between the effort required and the time taken to earn the reward, and makes it difficult to disambiguate the mechanisms involved in assessing effort-associated costs from those involved in assessing temporal costs. Three studies are described that attempt to do this.

Methods: The subjective value of 150 µl sucrose solution was measured in rats (N = 8/group) using a psychophysical procedure (the adjusting amount procedure: Richards, Mitchell et al 1997, J Exp Anal Behav 67: 353). For the delay group, the delay to receipt of the reward varied (0, 2, 4, 8, or 16 s). For the effort group, the effort [force multiplied by time exerted] required to earn it varied (0.01, 0.15, 0.35, 0.60, 0.90 Ns). Subjects received systemic injections of raclopride, a D2R antagonist (Experiment 1), or SCH-23390, a D1R antagonist (Experiment 2). In a third study, the requirements for the delay and effort groups were yoked to the performance of subjects required to complete difference numbers of responses to earn the 150 µl sucrose reinforcer (Response Group: 1, 2, 4, 8, 12, 16 responses) and systemic injections of raclopride were administered.

Results: For all experiments, the subjective value of the 150-µl reward declined systematically as a function of increasing cost. The degree of discounting was dose-dependently augmented by raclopride for the delay group (Exp 1 & Exp 3) and the response group (Exp 3), and was augmented only for the effort group for the SCH-23390.

Conclusions: These results suggest when the work costs of earning reinforcers are varied by manipulating the number of responses performed, mechanisms involved in assessing the temporal costs of behavior are critical. When the work costs are manipulated by permitting the requirements to be met by altering response topography, including the force exerted during performance, the role of dopaminergic receptors is not the same.

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Executive Control of Intertemporal Choice:
Effects of Cognitive Load on Impulsive Decision-Making

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Intertemporal choice involves trade-offs between costs and benefits over time. Two distinct neural systems are hypothesized to interact during intertemporal choices: the more “patient” cortical structures [including dorsolateral prefrontal cortex (DLPFC)] and the “impatient” limbic structures. The DLPFC has been shown to have a distinct role compared to limbic regions during intertemporal choices [1]. Further, the DLPFC, which is crucial in planning and goal representation [2], is likely to play an important role in discounting and intertemporal choice. This research examines the role of DLPFC and executive processes by increasing demands on cognitive processing on impulsive decision-making.

If the DLPFC and executive control processes are necessary for evaluating delayed rewards during intemporal choice, then engaging participants in a task that competes for the executive functions of working memory (WM) should result in increased impulsive decision making during an intertemporal choice task. Previous research on the effects of WM load on impulsive decision-making has been inconclusive because of concerns about erratic responding while under load. Participants in the present research performed intertemporal choices while simultaneously performing an N-back task under high load (3-back) or low load (0-back). A stair-casing algorithm allowed scrutiny of choices relative to participants’ point of indifference.

Decision making changes as a function of load such that participants in the high load condition chose the immediate reward more often than those in the low load condition. Thus, imposing a WM load limits evaluation of delayed reward, resulting in more impulsive decision-making.

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Cuing of post-reward delays substantially reduces impulsivity in macaques in an inter-temporal choice task

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The widely observed tendency for animals to prefer smaller, sooner rewards to larger, delayed rewards now stands as a cornerstone of animal psychology. Nevertheless, the ubiquity of natural behaviors requiring patience, such as food caching and prey selection, has proven difficult to reconcile with steep discounting rates observed in laboratory tasks. One possible explanation for this discrepancy is that standard delay discounting tasks artificially inflate impulsivity by presenting animals with contingencies they do not fully understand. To test this hypothesis, we examined choices made by rhesus macaques in two variants of a standard delay discounting task. In the more conventional variant, post-reward delays were both uncued and adjusted to render total trial length constant; in the second, all delays were cued explicitly. If monkeys are capable of learning the post-reward delay contingency, preferences should be the same in both tasks. Nonetheless, we found that impulsivity measures were substantially reduced in the cued paradigm, below those reported in analogous studies without explicit cuing of delays. Thus, when the post-reward delay was cued explicitly, monkeys predominantly made decisions consistent with reward rate maximization. These results suggest that monkeys, and perhaps other animals, are more patient than is normally assumed, and that laboratory measures of delay discounting may inadequately capture patience necessary for survival in the wild. Moreover, the observation of a large task-dependent component in impulsive behavior casts doubt on the idea of a single, fundamental discounted utility signal encoded by the brain.

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Single frontal neurons encode probabilistic reward prediction errors

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Objective: A much studied reward signal, implicated in learning, is that encoded by dopamine (DA) neurons. These neurons encode a prediction error (PE) signal, which is the difference between the expected and actual outcome. Prediction error activity has been reported in subcortical structures which receive DA input. However, while frontal areas like the anterior cingulate cortex (ACC), lateral prefrontal cortex (LPFC) and orbital frontal cortex (OFC) all receive robust DA input and all have been implicated in reinforcement learning and decision-making, it remains unclear whether these areas encode PE signals which may underlie their role in learning.

Methods: We trained two rhesus macaques (*Macaca mulatta*) to make choices between two pictures associated with different probabilities (0.3, 0.5, 0.7, 0.9) of obtaining a fixed amount of reward. We simultaneously recorded the activity of 610 neurons (257 from LPFC, 213 from ACC and 140 from OFC) while subjects made their choices and monitored the outcomes. Neuronal activity was examined in two different epochs: the first 1000ms following picture presentation (choice epoch) and 1000ms following outcome onset (outcome epoch). The outcome epochs were subdivided based on whether or not the outcome was rewarded.

Results: DA neurons encode the expected probability of reward prior to the outcome as well as the violation of that expectation (PE) during the behavioral outcome. We therefore identified neurons that encoded probabilistic value during the choice epoch and encoded the violation of that expectation (PE) in the outcome epochs. For rewarded outcomes, the activity of 25% of ACC neurons directly correlated with the size of the PE, exhibiting the largest change in firing rate when low probability of reward trials (0.3 probability) were rewarded and showing little change in activity when the highest probability of reward trials (0.9 probability) were rewarded. For unrewarded outcomes, the activity of only 9% of ACC neurons directly correlated with the size of the PE, exhibiting the largest change in firing rate when the highest probability of reward trials (0.9 probability) were not rewarded. Less than 5% of all neurons in either OFC or LPFC exhibited PE activity on either rewarded or unrewarded trials.

Conclusions: These results suggest a functional specialization within the frontal lobe, with ACC specialized for encoding probabilistic value during both the choice process and during the experienced outcome. Moreover, ACC activity resembles DA activity but only for encoding PE on rewarded trials, suggesting a functional link between ACC and DA for reward-guided reinforcement learning.

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Role of orbitofrontal cortex in confidence judgments in rats

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A fundamental component of decision making under uncertainty is the ability to assign appropriate levels of confidence to each decision. Recently we established that orbitofrontal cortex (OFC) carries neural signals about decision confidence in rats using a combined behavioral, electrophysiological and computational approach. Although we observed neural correlates of confidence in OFC, it may be one of several nodes in a network subserving confidence-guided decisions. Interestingly, however, several studies have shown that humans with OFC lesions are insensitive to the degree of uncertainty, indicating that the OFC may be causally involved in some uncertainty-guided behaviors. To understand the role of OFC in confidence judgments we designed a new confidence reporting task in rats and tested the impact of OFC inactivation on this task.

Rats were trained in a binary odor mixture categorization task. By interleaving trials of different odor-mixture ratios we could adjust the difficulty of individual decisions. Rats' performance accuracy ranged from over 90% for pure odors to chance levels (50%) for odors at the category boundary. To obtain a quantitative trial-by-trial estimate of rats' decision confidence, we measured the length of time rats were willing to wait in the reward port when the normal water reward was not delivered and compared this to predictions of decision confidence models (Kepecs et al., 2008). We first observed that for incorrect choices, rats waited longer on difficult (uncertain) trials compared to easy (certain) trials, as predicted by confidence models. We then introduced catch trials in which reward was omitted for correct answers. Overall, rats waited longer for correct catch trials compared to error trials. Moreover, they waited longer for easy (certain) catch trials compared to difficult (uncertain) catch trials. This pattern of data is in accord with our hypothesis that rats' willingness to wait for a reward is proportional to their confidence about the correctness of their sensory decision.

To test the causal role of OFC in this confidence-reporting task, trained rats were implanted with bilateral cannulae in lateral and ventrolateral OFC. On each testing day, rats received an infusion of either the GABA agonist muscimol or a saline control solution. OFC inactivation produced a partial but significant reduction in the dependence of reward waiting time on decision confidence without changing sensory discrimination performance. These results provide preliminary evidence for the causal involvement of OFC in confidence estimation and establish a behavioral assay suitable for examining the neural mechanisms underlying this process.

Value-based gain control: a model of context-dependent choice

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One of the hallmarks of rational choice theory is that decisions are determined solely by the independent values of the choice options. However, growing evidence from economics, ecology, and psychology indicates that decision-makers often violate these assumptions, with choice behavior dependent on the different options available. Specifically, decision-makers have difficulty with large choice sets: in both laboratory and field studies, a large number of alternatives induces suboptimal selection and increased rates of defaulting out of making a decision. Such context-dependent preferences are important because they represent decision behavior that cannot be explained by normative theory alone; knowledge of the underlying neurophysiological mechanism is necessary to fully describe function.

We have recently explored the representation of value information in the decision-making process. In the lateral intraparietal area (LIP), visuomotor neurons are strongly modulated by reward variables such as expected gain, prior probability, and reward income, suggesting that individual LIP neurons represent the subjective value of specific saccades. In this decision framework, population activity initially encodes the values of the available targets; comparison of these values results in action selection and output of choice information to downstream oculomotor structures. Our recent work shows that LIP value representations are relative, not absolute, and depend on both the value of the encoded action as well as the summed values of all the alternatives in the choice set. Furthermore, this relative representation appears to be implemented by a well-known cortical computational algorithm known as *divisive normalization.*

We present here: 1) behavioral results demonstrating value-guided, context-dependent preference in monkeys, and 2) a computational results demonstrating that a reward representation based on divisive normalization generates qualitatively similar results. We trained monkeys in a three option choice task: in each trial the monkey viewed three targets, two targets (A,B) associated with relatively large magnitude rewards and a third target associated with lower magnitude reward (C). Reward contingencies and target locations were fixed within a block, and varied between blocks in the following manner: reward A was fixed (0.156 ml), reward B was smaller, equal to, or larger than A (0.130-0.182 ml), and reward C was one of two smaller magnitudes (0.026, 0.104 ml). Visual stimuli were identical and spatial locations were randomized between blocks to encourage the monkeys to choose based on value alone. We find that changing the value of the irrelevant alternative (C) specifically affects the slope of the choice function between A and B. Importantly, these results show that context-dependent value effects can be quantified as a change in the value representation: increasing the irrelevant third option value effectively changes the noise in the decision task, making it more difficult to discern the higher of the two target options (A or B). Analogous to the change in the slope of the psychometric function in sensory psychophysics, the change in the value-dependent choice curve suggests that additional alternatives affect valuation by decreasing the discriminability between the option values. The specific form of this effect on the choice curve suggests that the framework of signal detection theory can be adopted to study value-guided oculomotor decision-making. We also present results from a computational model of decision-making that incorporates: 1) value normalization parameters fit to neurophysiological LIP data, 2) Poisson-like variability in neural firing rates, and 3) a stochastic choice mechanism. These computational results suggest that a relative value mechanism in the context of intrinsic neural variability is sufficient to generate context-dependent choice.

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Dissociable Neural Signals for Valuation and Salience at the Time of Decision Making

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Background: In order to make a decision the brain needs to assign a *value* the different options under consideration, which can then be compared in order to make a choice. A difficulty in characterizing neural value signals is that in most studies they are highly correlated with salience and attention. We use a novel human fMRI experimental design that orthogonalizes both types of signals, and thus allow us to dissociate the neural representations of these two types of processes.

Methods: 20 right-handed participants encountered a series of 240 food item images. On each trial, they indicated (within a 2s interval) their willingness to eat the presented food item at the experiment's end using one of four responses: "Strong No", "No", "Yes", or "Strong Yes". Participants were informed that a random trial would be selected at the experiment's conclusion, with their response on that trial dictating whether they would be asked to eat the selected item. A crucial feature of the design was that it included both appetitive and aversive food items.

Results: BOLD activity correlated with the value of items in the medial orbitofrontal cortex, rostral anterior cingulate, and dorsal posterior cingulate. In contrast, BOLD activity correlated with salience (as measured by the absolute value of the value regressor) bilaterally in the posterior insula, dorsal anterior cingulate, and supplementary and primary motor areas. Both processes engaged nucleus accumbens (NAcc), with indication of anatomically distinguishable sub-regions modulated either by valuation or salience.

A Bayesian account of the role of attention in value-based decision-making.

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A central question in Neuroeconomics is how are values computed and compared during decision-making.

We propose a generative model of the problem that the brain faces at the time of decision. In particular, we argue that the problem can be described as a Partially Observable Markov Decision Process (POMDP) in which the decision-maker trades off achieving the immediate expected utility of choosing an item with the imperfect information that he has, over gaining more information about the items that might lead to better choices later. We test the predictions of the model using an eye-tracking experiment in which subjects make choices over pairs of food stimuli.

We fit the model to the data using Bayesian methods and show that its predictions match the psychometric and eye-movement patterns predicted by the normative model quite well. Among others, the model accounts for an increase in reaction times and number of fixations as the value of items become closer, and differences in the duration of the middle and last fixations.

Furthermore, the model predicts that it should be possible to by manipulate choices by altering the path of visual attention, which is consistent with the experimental findings of Armel and Rangel, 2008.

The Relative Role of Visual Saliency and Value in Rapid Saccadic Choice

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Objective: Imagine that you are in front of a vending machine with a few seconds available to purchase a food item. The available items vary both in subjective value - how much you like each - and in their visual attractiveness or saliency. In the current work, we examine the nature of the interaction between value and saliency.

In our recent eye-tracking study, subjects made a choice between two food items with different subjective values, as indicated by a priori subject's liking ratings for each item (Milosavljevic, et al. 2009). The results from 7 subjects indicate that simple value-based choices can be made accurately (85.7%), with a mean reaction time of 582 ms. At the same time, it is known that during free-viewing saccades are influenced by visual properties of stimuli, such as saliency (Parkhurst & Niebur, 2003). There are two questions that we examine in the current work: (1) What is the relative contribution of value and saliency to value-based saccadic choice? and (2) Does the relative importance of these two factors change with the amount of time spent making the choice?

Methods: In the current study, subjects made saccadic choices between high-resolution images of snack food items with different subjective values, as indicated by a priori subject's liking ratings for each item. Nine items (3 by 3 grid) were displayed on the left and the other nine items on the right side of the screen. The stimuli were shown simultaneously for different presentation durations, blocked at 70 ms, 100 ms, 200 ms, 300 ms, 500 ms. Following stimuli presentation, a mask appeared over all the items. Subjects indicated their choices between previously displayed items located at the center on the right, and the center on the left, by making a saccade toward the side where the preferred item appeared. To manipulate the saliency of the items we changed the relative brightness of the images, so to make one of the two options pop out.

Results: The results from 7 subjects (1050 trials each) indicate that the effect of visual saliency on choice declines with time, while the effect of value on choice increases with time and does not saturate until 500 ms. Further, saccadic choices are driven by options' value when one item is strongly preferred to the other, irrespective of saliency manipulation. However, when the two items are of similar value to subjects, there is a significant effect of visual saliency early on (<200ms, $p<.01$, 2-tailed t-test).

Conclusions: In sum, the effect of saliency on value-based choice is strongest for very fast decisions, but does not go away for computation times as long as 500 ms, when value completely takes over.

Cognitive modulation of goal values at the time of decision making

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Over the last few years, research in decision-making has evolved from a simplistic view of emotion as an impediment to good decision-making toward a view in which emotions have the potential to both improve and impair decision making. This realization has led to increased interest in the processes by which people flexibly control their emotions, although it is unclear the extent to which the affective processes informing decision making are under conscious, intentional control.

To examine how neural control processes modulate the conversion of inherent preferences into decision value, hungry subjects provided baseline preferences for different junk foods and then were trained to deploy three different types of regulatory strategies when encountering the food: (1) natural response (2) indulgence, and (3) distancing. In the scanner, participants indicated how much they would be willing to pay to consume the different foods (Plassmann et al., 2007), while employing these three regulatory strategies.

Behaviorally, indulgence increased food value compared to natural response (mean increase \$0.22, $p < .001$), while distancing had the opposite effect (mean decrease \$0.22, $p < .001$). Although the magnitude of the shift in bids was similar in both cases, fMRI results suggested that these effects emerged from different processes. While indulgence increased the correlation between baseline preferences and activation in the ventral striatum, distancing decreased the correlation between preference ratings and a region of the rostrolateral prefrtonal cortex implicated in the computation of goal value (Plassmann et al., 2007). Moreover, whereas indulgence resulted in little recruitment of prefrontal regions involved in executive control, distancing resulted in the strong recruitment of bilateral inferior frontal gryus.

These results suggest that participants can use cognitive strategies to modulate basic valuation systems at the time of decision making, but that the mechanisms required to do so depend on the regulatory goal.

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Retrospective Evaluations in Capuchin Monkeys: The evolution of end-point sensitivity

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If individuals made economically rational choices, they would base their decisions on mathematical, context-invariant representations of real-world situations – like in the case of expected utility maximization. However, in many laboratory and real-world settings, people incorporate irrational contextual information into their decisions. Framing effects can also change decision makers' choices in situations that are interestingly different from those that are classically studied by economists: they influence peoples' retrospective evaluations of past events. Specifically, people's memory of pleasurable and painful events are subject to framing effects in that they are not strictly related to the overall quality of an episode, but instead depend on the end-point of that experience. Human participants rate surprisingly highly painful experiences as more tolerable than less severe ones, simply based on whether the more painful experience concludes with a better end-point. While there is a good deal of evidence of end-point sensitivity in humans, there is little evidence of this type or economic irrationality in non-human primates. If a non-human primate does show end-point sensitivity, it would suggest that end-point sensitivity evolved long ago, and is not a unique product of human language or culture. To address this question, we conducted a test of end-point sensitivity in capuchin monkeys (*Cebus apella*) using a trading task. Monkeys were given a choice between trading with two experimenters who offered the same food rewards, but one experimenter delivered the rewards with a high end-point, and the other offered delivered a low end-point. Monkeys preferred to trade tokens to receive a sequence of food rewards that provided the high point at the end of a sequence rather than the beginning. Thus, capuchin monkeys prefer an experience which provides them with a high end-point, just as has been observed in humans. Our results therefore suggest that monkeys also take into account subjective features of remembered experiences that are irrelevant to the absolute outcome of their choices. The observed results fit with a growing body of work suggesting that many of our own species' behavioral biases are shared with other primate species, even those that are distantly related in evolutionary time. This suggests that our behavioral biases do not necessarily emerge as a result of specific economic experiences and market disciplining—instead, our economic biases might be the result of evolved cognitive strategies, ones present in our primate lineage for considerable phylogenetic time.

Personal, generic and automatic: three core features of the brain valuation system

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Objective: According to classical economic theories, preference for one particular item among others reveals its value on a common scale. This framework suggests the existence of a brain system devoted to valuating the objects present in our environment, so as to provide a basis for subsequent choices. Previous studies brought evidence that ventral prefronto-striatal circuits may underpin such a brain valuation system (BVS). The objective of our study was to assess whether the BVS is 1) personal - encoding values that differ between individuals for given items, 2) generic - encoding values for various categories of items and 3) automatic - encoding values even when these values are not needed to perform the current task.

Methods: We showed a series of pictures pertaining to three different categories (faces, houses and paintings) to twenty healthy subjects during functional MRI scanning. We asked subjects to rate either the pleasantness (explicit task) or the age (distractive task) of the items following their display in the scanner. After the scanning session, subjects were asked to state their preference between the items presented two by two. We checked that preferences were stable within subjects but variable between subjects, and that the different tasks and categories activated different brain circuits.

Results: We could isolate a brain network - encompassing the ventromedial prefrontal cortex, the ventral striatum, the hippocampus and the posterior cingulate cortex - that meet the definition of a BVS. Indeed, activity in these regions both significantly correlated with explicit valuations (pleasantness ratings) and significantly predicted the preferences (binary choices). Moreover, prediction of preferences was significant whatever the category of pictures (faces, houses or paintings) and whether subjects were explicitly engaged in a valuation task (pleasantness rating) or a distractive task (age rating).

Conclusion: Ventral prefronto-striatal regions, with addition of hippocampus and posterior postulate cortex, qualify as a personal, generic and automatic BVS. These properties designate the brain valuation system as fundamental to account for decisions that depend not on perceptual evidence but on internal variables.

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Valuation in a Sequential Choice Task Utilizes Dorsomedial Prefrontal Cortex

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Objective: To dissociate the components of decision making, sequential choice paradigms have an advantage over simultaneous choice paradigms in that they disentangle the valuation of possible options from the comparison of those options' values. Hence to probe the underlying neuronal mechanisms in valuation, we have recorded from single neurons in dorsomedial and dorsolateral prefrontal cortex (PFdm and PFdl, respectively) as subjects performed a sequential choice task. We expected PFdm to encode the valuation of choice options, owing to its strong anatomical inputs from areas processing reward.

Methods: Two monkeys (*Macaca mulatta*) performed a task that required them to choose between two different juices on a trial-by-trial basis. During the sampling phase, the subject makes two sample responses separated by delays, each of which results in the delivery of a small drop of one of three juices (apple, orange or quinine). During the choice phase, the subject then chooses to repeat one of the responses, and receives a larger amount of the juice that was associated with that response earlier in the trial. Thus, in order to receive juices that are more preferable at the choice phase of the task, the subject has to maintain information about the first sampled reward and which response produced it to compare that reward to the subsequent reward.

Results: We recorded the activity of 112 PFdm neurons and 172 PFdl neurons as the subjects performed the task. Following the sampling of the first juice, a similar proportion of neurons encoded the action producing the reward in PFdm (46%) and PFdl (48%), whereas encoding of the juice reward was prominent in PFdm (60%) but not PFdl (28%). Reward-selective neurons showed a monotonic relationship between their firing rate and the subject's preference for the juice, suggesting that PFdm neurons encoded the juice as a value signal. PFdm neurons encoded the value of the second juice relative to the first, typically showing a higher firing rate when the second juice was less preferred than the first.

Conclusions: These findings suggest that options in a sequential choice are evaluated with respect to previous options. By maintaining the value of the first juice and then encoding the value of the second juice relative to the first, PFdm neurons provide the appropriate information to enable the subjects to make their choice.

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Supplementary eye field reflects both value and direction of the saccadic choice in a gambling task

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Decision-making depends critically on accurately estimating the value of each available option. Especially when the choice is risky, the value estimation gets more demanding since the expected value for each option not only depends on what the possible outcomes are but also on their probabilities. Therefore, the actual value of each option should be monitored as the outcome gets realized so that it can be used to update the value estimation of the selected option.

To study decision-making under risk and the dynamic representation of value it necessitates, we recorded single cell activities in the supplementary eye field (SEF) of two macaque monkeys during a gambling task. SEF has strong connections with limbic areas including orbitofrontal and cingulate cortex, and also with oculomotor areas, such as frontal eye field and superior colliculus. These rich anatomical connections with both value-representing areas and motor areas posit the hypothesis that the SEF might play an important role in value-based decision making.

Behavioral results showed that the monkeys made their choices based upon the expected values of the given options. Among the neuronal data recorded in the SEF, we found one group of task-related neurons whose activity appeared ~150ms before or around the time of the saccade initiation, i.e. during the time of decision-making. This type of activity reflected both the expected value of the chosen option and the direction of the saccade necessary to indicate the choice. This implies that the function of these neurons could be to guide the selection of a desirable motor action based upon the value information. We also found another group of task-related neurons that monitored the value of the choice following the saccade. One group of neurons represented the expected value of the current choice, during the delay time following a saccade and before the revelation of the outcome. Finally, after the result was shown, a second group of neurons indicated the absolute reward amount the monkey would get, while a third group reflected the relative value of the gamble’s outcome (win/loss).

Our results show that the SEF neurons reflect the value of a particular choice along the distinct stages of decision-making under risk. In addition to the value information, SEF also reflects the motor information necessary to specify a choice action. These findings imply that the SEF keeps track of the value of reward options and based on that estimation, guides the action selection during value-based decision-making involving the eyes.

Dynamical Bayesian computations of decision values in vmPFC

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Normative models of decision making suggest that organisms should incorporate information from the environment into their valuation computations using Bayesian procedures. However, little is known about how and where the brain performs such calculations.

In this study we used fMRI in humans (N=20) to investigate this question. Subjects performed a binary choice task between a lottery and a fixed certain reward. The key aspect of the experiment was that the value of the lottery was revealed sequentially. In particular, in every trial the subjects observed up to 3 symbols presented sequentially, and each symbol carried unique information about the lottery option. Hence, an optimal Bayesian decision maker should update the value of the lottery dynamically as the symbols are presented.

We found that subjects' choice behavior was well described by an optimal Bayesian updating model. Furthermore, preliminary fMRI results indicated that the ventro-medial prefrontal cortex (vmPFC) encodes the updated value computation for the lottery predicted by the Bayesian computation.

A number of previous studies have shown that the vmPFC encodes a value signal at the time of choices that might be used to make goal-directed decisions. The results in the current study show that this value signal is computed dynamically in a way consistent with optimal Bayesian updating, thus providing further insight into the computations performed by this area during decision making.

Asymmetric BOLD responses to positive and negative outcomes

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When making decisions about lotteries with potential monetary gains and losses, people are typically more sensitive to potential losses than equivalent gains. Tom et al. (2007) found that BOLD responses in the ventral striatum and medial prefrontal cortex were modulated more by potential losses than gains and that the degree of this asymmetry correlated with the individual degree of behavioral loss aversion. BOLD responses in both areas are thought to encode reward prediction errors for experienced outcomes. However, no lotteries were resolved during this experiment and it is unknown whether BOLD responses to experienced outcomes also reflect the behavioral asymmetry in choice. We used functional MRI to measure BOLD activity in a task where subjects received monetary prizes. Subjects ($n = 12$) were endowed with $100 at the beginning of each of two scanning sessions. In each trial, subjects pressed a button to select one of two visually presented lotteries and then immediately played that lottery. For example, a subject might choose a lottery with equal probabilities of winning or losing $5 and then, after a brief delay, find out that they won $5. In separate regressions, we identified brain areas where BOLD responses correlated with expected prediction error magnitude for positive and for negative outcomes. A conjunction analysis identified significant regions of overlap in the bilateral ventral striatum, bilateral amygdala, and medial prefrontal cortex ($P < 0.005$). We found that BOLD responses in each of these areas exhibited a greater degree of modulation for negative outcomes than equivalent positive outcomes. We verified the neural asymmetry in these three areas with anatomically defined regions of interest. This asymmetry in BOLD responses to gains and losses raises the possibility that neural responses to experienced outcomes might reflect behavioral loss aversion.

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Seeking rewards and avoiding punishments over the adult life span

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Objective: A large body of work reveals a steady decline in fluid cognitive processing capacity over the adult life span, but a robust preservation of the processing of emotional stimuli – particularly for positive material. Both behavioral and neural evidence suggests that younger and older adults differ in the affective processing of monetary incentives. Older adults show attenuated anticipation of monetary losses in the caudate and insula, and individual differences (controlling for age) in insular activity predict loss avoidance learning. However, in previous studies small sample sizes did not allow for reliable estimates of age differences in learning. Extending these prior findings, here we examined age differences in learning to seek gains and avoid losses in a large sample of adults.

Methods: Eighty-five healthy adults (ranging in age from 20 to 85) participated in the study. Each subject played a probabilistic learning task with separate trials for learning about gains and losses. The task was incentive compatible and all subjects were paid in cash. After completing the task subjects also rated their affective reactions to the cues.

Results: As expected, we found that although gain learning did not change, loss avoidance learning declined with age. Post-task affective cue ratings revealed that younger adults distinguished between all gain and loss cues. However, consistent with the learning impairment, ratings of the loss cues did not significantly differ from ratings of neutral cues in the older adults.

Conclusions: This study provides evidence that the age-related positivity effect extends into financial decision making. Although these affective preferences may be healthy and adaptive for regulating emotional experience and optimizing well-being, they may have harmful effects on financial learning and decision making. Future work will explore the neural systems underlying these age-related biases in a subset of these subjects who completed the task while undergoing fMRI.

Acknowledgements:
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The Contingency of Gain and Loss Influences Decision Making in a Modified IGT

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To clarify the effects of risk level and expected value in decision making, Yen, Kao, Chou, & Chung (2009) developed a modified IGT (IGT-M), in which the expected value and risk level were manipulated separately. In good decks, the immediate gain and delayed loss were smaller, which led to positive expected values. In bad decks, the immediate gain and delayed loss were larger, which led to negative expected values. The risk level was manipulated by the magnitude of coefficient of variation. For the same expected value conditions, the mean of punishments was kept the same, but the variation of punishments was different. Simply stated, the high risk decks were associated with a larger range of variation than the low risk decks. Behavioral and SCR data were collected and a significant interaction between expected values and risk levels was found. Participants chose more cards from risky deck in bad decks, and chose more cards from less risky deck in good decks. Furthermore, the SCR data showed the same pattern as the behavioral data. However, different contingencies of the rewards and punishments may influence participants' decision strategies. The strategies are different between immediate steady gain followed by delayed unsteady loss and immediate steady loss followed by delayed unsteady gain (Kahneman & Tversky, 1984 ; Windmann et al., 2006). A reversed contingency schedule of IGT-M (IGT-R) is used in the present study. That is, in IGT-R, there is immediate loss on every trial, while the delayed gain appears from time to time. In specific, good decks are with high immediate loss and positive expected value, whereas the bad decks are with low immediate loss and negative expected value. All the other factors are as same as IGT-M. The results revealed that participants chose more good decks than bad decks and higher anticipatory SCR was shown before the choice of good decks than bad decks. In other words, participants behaved quite differently in IGT-M and IGT-R. To further understand whether the underlying decision processes are different in these two tasks, parameters estimated from a decision model proposed by Ahn, Busemeyer, Wagenmakers, & Stout (2008) were compared.

Keywords: risk level, expected value, reversed contingency, cognitive modeling

‘The Neuroeconomics of Money’

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Money is a powerful force in our lives. The neoclassical economic assumption concerning the goal of the firm is that companies maximize profit. That is, it is all about money. Further, the microeconomics of consumer utility states that more consumption (bought by money) is always better than less consumption. Therefore, it is not only useful but critical to analyze decision-making by individuals and by executives in firms to understand how money activates the brain’s dopamine-mediated reward system. In addition, certain individuals can actually become addicted to money, depending on their genetic makeup. The author will present a synthesis of the current research into the neuroeconomics of money. He will also present his own conclusions about money from his research in neuroscience, psychology, economics and philosophy.

Current neuroeconomics characterizes money as both a ‘tool’ - an interest in money for what it can be exchanged for - and a ‘drug’ - an interest in money for itself, a maladaptive function (Lea & Webley, 2006). The tool aspect further emphasizes that people value money for its instrumentality – that is, money enables people to achieve goals without aid from others. Contrariwise, Price et al. show that physical and mental illness after financial strain due to job loss is triggered by reduced feelings of personal control (Price et al., 2002). The drug aspect emphasizes the maladaptive desire for money and how an individual can actually become partially or fully ‘addicted’ to money. The author will elucidate both these aspects, including a neurological discussion of how money can cause addiction in the brain’s dopamine reward system.

Pessiglione et al. devised experiments to show how the brain translates money into a force (Pessiglione et al., 2007). The fMRI brain scans showed activity in a specific basal forebrain area that includes the ventral striatum - the reward center of the brain (the dopamine processing brain facility), ventral pallidum and extended amygdala. More specifically, O’Dougherty et al. and Pessiglione et al. have shown that ventral striatum activity has been linked to reward prediction and reward prediction error during learning (O’Dougherty et al., 2004; Pessiglione et al., 2006).

Further, Vohs and his colleagues found that participants who were primed with the concept of money preferred to work alone, play alone and put more physical distance between themselves and a new acquaintance (Vohs et al., 2006). Similarly, Grouzet et al. show that across 15 different cultures, ‘financial success’ as a goal is in direct opposition to goals concerning ‘community’ (Grouzet et al., 2005).

Despite the neoclassical economic assumption that more money is always better than less money for the individual – that is, brings higher ‘utility’ or satisfaction - extensive research shows that large amounts of wealth have little or no effect on life satisfaction. This is true both across national studies and in time-series studies (Seligman, 2002; Diener and Seligman 2004). The author will explain why this occurs.

Why hire a broker? Neuroeconomic factors and financial decision making

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Objective: Many investors pay brokers or financial advisors for financial advice. Bergstresser, Chalmers and Tufano (BCT) attempts to quantify the benefits that investors receive in exchange for the costs of these services by studying broker-sold and direct-sold mutual funds from 1996 to 2004. BCT fail to find that brokers deliver substantial tangible benefits. Specifically, broker-sold mutual funds underperform mutual funds that are sold directly, they cost substantially more, and brokers do not appear to attenuate potentially costly investor behaviors. Nonetheless, about $2 trillion of the $6 trillion in mutual funds sold every year are sold by brokers. Either a large fraction of investors are making repeated mistakes dealing with these brokers, or there are some benefits that are not well understood.

Methods and results: Using behavioral data and fMRI scanning during simulated investment decisions, we study the role of cognitive and emotional factors on the decision to seek advice, and on the neural correlates of decisions made with and without broker input. Our sample consists of 20 university staff members who made their decisions both privately and while observed by their spouses/partners. Participants were shown a series of investment choices and had the option to make a choice themselves or hire a simulated broker to help make their choice. In our preliminary analysis we find wide variation in our subjects' propensity to use a broker. The relative risk difference between the stocks is highly predictive of the subsequent choice to use a broker, suggesting that risk attitudes may be a primary determinant of broker usage. Preliminary analysis of imaging data shows that the subjects who choose brokers most frequently generally show less activation in the nucleus accumbens and caudate during the decision phase of the experiment than the people who typically make decisions themselves. This is consistent with the hypothesis that subjects differ in the intrinsic neural rewards of solving investment decisions, and that these differences help drive the decision to seek advice. These results imply that neural data may be helpful in designing the presentation of financial information to be most effective for individuals of these two types.

Acknowledgements:
Funding for this project has been provided by NIH and by generous gifts by Gerry and Marilyn Cameron and Abbott Keller who support Chalmers.

References:

Bergstresser, D., Chalmers, J. M. R. and Tufano, P. 2008. "Assessing the costs and benefits of brokers in the mutual fund industry" forthcoming in *The Review of Financial Studies.*

Using a computational phenotype to investigate the genetic basis of decision-making under risk

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Abstract:

Behavioral studies of decision-making under risk have shown significant variation in an individual's willingness to take risks. This has led many to conjecture that some of this variation may be attributable to genetic differences. In this project we investigate the role that functional polymorphisms of the following three genes might play in risk-taking behavior: 5HTT, MAOA, and DRD4. We focus on these three genes because previous studies have implicated these polymorphisms in contributing to a variety of risky personality traits including impulsivity, novelty-seeking, aggression, and pathological gambling.

In the study N=90 males were asked to make decisions between a risky gamble and a risk-free alternative in 140 separate trials. We found that males carrying the low expression variant of the gene encoding monoamine oxidase A (MAOA) engage more frequently in the risky choice (41%) than those carrying the high expression variant (35%, $p<0.001$.) In contrast, there were no significant differences between the polymorphisms for the 5HTT and the DRD4 genes.

A novel feature of the study was that our gamble selection allowed us to estimate the underlying computational parameters characterizing the decision processes of each subject. This provided us with an additional computational phenotype that allowed us to investigate not only if a given polymorphism affects risk-taking behavior, but also through which psychological mechanisms. This analysis revealed that individuals with the low variant of the MAOA gene engage in more risk taking behavior not because they weight risks less in their decisions (i.e., they are not less mathematically risk averse), but because they value potential gains significantly more (i.e., they are more aggressive in seeking out high payout options). Using this same analysis we did not find any impact of the 5HTT and DRD4 genes on the computational phenotype.

Individual and genetic differences in risk preference and loss aversion

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Objective: This experiment had two aims. First, we assessed individual economic preferences across multiple task and survey measures, and determined the interrelationships of these different measures across the population to identify major axes as behavioral phenotypes. Secondly, we acquired genetic material that will relate these phenotypes to neural differences associated with neurotransmitter pathways.

Methods: Over 300 subjects (ages 18 to 78, ~60% female and 60% Caucasian) have participated in this study. Each subject performed three incentive-compatible tasks to determine economic preferences for uncertainty (risk and ambiguity), loss aversion (lambda), and risk allocation (maximization vs. heuristics). Additionally, subjects filled out multiple behavioral surveys related to decision making: Decision-Making Style Inventory, Temperamental Character Inventory, Domain-Specific risk, Maximizing/Satisficing, Need for Cognition, and Barratt Impulsivity Scale.

Additionally, we collected a saliva sample from each subject, which will be used to examine the relationship between specific genotypes and economic preferences. We selected candidate polymorphisms from genes within the serotonergic and dopaminergic systems, including: DAT1 (40bp VNTR), DRD4 (48bpVNTR), DRD2 – Taq1a, 5HTTLPR (long/short), SLC6A4 Stin2, COMT (Val158Met SNP), and MAO-A (uVNTR).

Results: We have identified two independent behavioral factors. *Uncertainty Preference* was calculated by determining the risk and ambiguity premiums necessary to raise the expected value of an uncertain gamble to an equivalent certain option (e.g., certainty equivalent = risk premium * expected value of gamble). On average, we found the risk premium to be 1.5 (sd: 0.62), and the ambiguity premium to be 2.03 (sd: 0.76). Risk and ambiguity premiums were highly correlated within subjects ($r = 0.63$), and thus constitute a single factor. *Loss Aversion*, the relative weighting of losses and gains (lambda), was calculated from independent task data. On average, subjects weighed losses 2.6 times as strongly as gains (average lambda: -2.6). *Uncertainty preference* and *Loss Aversion* were only weakly correlated across subjects (below |.15|).

Conclusions: Two clear and independent phenotypes have emerged from our tasks, *Uncertainty Preference* (risk/ambiguity premiums) and *Loss Aversion*. These phenotypes are well-suited for our genetic analyses.

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Which neural reactions do negative payoffs cause in risky decision making?

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Abstract

Decision making under risk as modeled in Prospect Theory is based on a utility function with three main characteristics: risk aversion for gains, loss aversion when comparing gains and losses and risk loving behavior for losses. The first two aspects have been tested extremely well with a lot of techniques. This is possible since over a whole session participants do not face losses. Losses are always temporarily in these studies and compensated either way. Since in economic contexts decision have to be made concerning real losses, especially in times of economic depression, this prediction of Prospect Theory is extremely important. Risk loving behavior is modeled by means of a utility function which is a tool describing preferences, but does not inform about emotions or other reactions concerning money. Testing the prediction of risk aversion in the laboratory is difficult since participants are facing losses. One paradigm typically applied is to give money to subjects some days before testing which covers all potential losses in the lottery decision. Another paradigm is to combine possible gains and losses in such a way that the overall payoff is positive. These procedures do not really induce the feeling of a loss since participants leave the laboratory with positive payoff in total which they know in advance. In contrast to previous investigations our participants, recruited from a university seminar, had to pay losses up to 50 Euros for real without any compensation. We analyze the choices in binary lotteries in which the chance to receive a payoff of 0 is 0.5 and the chance to face a loss of 50 Euros is also 0.5. In our experiment participants had to choose between playing this lottery or paying a fixed amount x. This amount varied between -1 and –50 Euros. One of their choices was randomly selected and had to be paid at the end of the session. Seventeen subjects were scanned using a slow event related functional MRI to investigate the neural underpinnings of loss related decision processes. We compared the fMRI data for losses with fMRI data for gains we collected in another study with fifteen subjects using a similar design in which participants had the choice between a binary lottery in which 100 Euros or 0 Euros could be won or a fixed positive amount of money. By contrasting decisions near the indifference point with decisions in which subjects have chosen a lottery or a loss/win for sure activations in the anterior cingulated cortex in both paradigms were observed, whereas subcortical and amydgala activations differentiated between paradigms. Interpreting our data is that human beings resist to pay a negative amount of money. Instead of doing this they prefer playing a lottery.

Is brain activity observable that leads to an evaluation of a probability of 0.5 that is different from 0.5 in binary lottery choices?

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Abstract

This paper focuses on the problem of probability weighting in the evaluation of lotteries. According to Prospect Theory a probability of 0.5 has a weight of smaller than 0.5. We conduct an EEG experiment in which we compare the results of the evaluation of binary lotteries by certainty equivalents with the results of the bisection method. The bisection method gives the amount of money that corresponds to the midpoint of the utilities of the two payoffs in a binary lottery as it has been shown previously. In this method probabilities are not evaluated. We analyzed EEG data focused on whether a probability is evaluated or not. Our data show differences between the two methods connected with the attention towards sure monetary payoffs, but they do not show brain activity connected with a devaluation of the probability of 0.5.

Measuring Strategic Uncertainty and Risk in Coordination-, Entry-Games, and Lotteries: an fMRI study

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Abstract

Objective: The question we are addressing is whether the neural systems mediating decisions in individual and social context are distinct. In other words, are the choices in games and lotteries mediated by different neural systems and brain areas? We measured brain activity using fMRI while subjects selected between two options in a Lottery, Coordination and Entry game.

Methods: In the lottery, a subject has to choose between a given sure payoff and a lottery which gives 0 with probability 1/3 and 15 Euros with probability 2/3, while in the game situations (Entry or Coordination games) a player chooses between the same sure payoff and a game in which it depends on 2/3 (k) of the other players whether he gets 0 or 15. In the Entry game, subjects are rewarded 15 Euros if at most k persons chose B, whereas in the Coordination game, subjects receive 15 Euros if at least k persons chose B. Across the experiment we varied the probability of the risky option in the lottery; k and number of players in the games.

Results: We found enhanced activity in bilateral anterior insula related to outcome uncertainty. Activity in the medial prefrontal cortex (mPFC), superior temporal sulcus, and temporo-parietal junction, and posterior cingulated cortex was related to playing in coordination and entry games. Increasing strategic uncertainty was correlated with neural activity in the mPFC.

Conclusions: Our results suggest that a common neural substrate (anterior insula) is shared in the individual and social contexts for the resolution of uncertainty. Moreover, the pattern of activity in the mPFC revealed the fundamental role of this area in strategic reasoning.

Coding of risk and expected value by distinct neurons in the orbitofrontal cortex

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Objective: Risky decision-making is altered in humans and animals with damage to the orbitofrontal cortex, yet the function of the intact orbitofrontal cortex in processing information relevant for risky decisions is unknown. We recorded responses of single orbitofrontal neurons while presenting monkeys with cues representing the key decision parameters: risk (statistical variance of reward) and expected (mean) reward value.

Methods: Two male macaques performed an eye movement task for a juice reward. The monkeys fixated on a spot in the centre of a computer monitor while visual cues were presented to the left or right of the spot. The vertical position of horizontal bars on the cues predicts the amount of juice to be delivered. There is a single bar on the expected value cues that fully predicts ($p = 1$) the juice volume. The risk cues have two bars predicting either a low or high volume of juice with equal probability ($p = 0.5$). Monkeys risk preference was assessed in choice trials where safe and risk cues were simultaneously presented and the monkeys indicated their preference by eye movements. We then recorded from single neurons while presenting the monkeys with the risk or expected value cues.

Results: Monkeys preferred the riskier options to the safe option. This suggests the monkeys attach a subjective value to the risk associated with the cues. We recorded 262 task-related orbitofrontal neurons that showed statistically significant activation with at least one task event (cue, saccade, key release, reward). Of these, 99 neurons (38%) showed significant correlation coefficients for risk. Since the monkeys preferred the higher risk options it was necessary to further characterize the neuronal responses as reflecting a risk signal *per se* or a behavioral preference/value signal. In a subset of neurons recorded, we presented monkeys with the three expected value cues as well as the risky cues. The majority of responses from the neurons sampled were risk- (34/149, 23%) or expected value- (104/149, 70%) sensitive. A small subset (11/149, 7%) of neuronal responses had significant correlation coefficients for both risk and expected value, with 6/11 correlation coefficients sharing the same valence (i.e., less than 5% (6/149) of the overall population of responses shared the same signed correlation coefficients for risk and expected value).

Conclusions: These results show that distinct groups of orbitofrontal neurons code risk or expected value but not both, suggesting neural coding of decision parameters compatible with the mean-variance approach in financial decision theory.

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Neurometric Predictors of Risky Decision Making in Children

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Objective: Previous imaging studies with adult participants have found specific regions of prefrontal cortex (PFC) and posterior parietal cortex (PPC) to be associated with risky decision making [1-5]. However, studies of risky decision making in children have been relatively few in number, and fewer still are those examining individual differences [6]. The current study tested 6- to 7-year-old children in a risky decision paradigm that manipulated risk level and expected value.

Methods: Children made decisions involving a choice between one of two Sure Bet values or between a Sure Bet and a Gamble, while event-related fMRI data was acquired, with the goal of collecting coin tokens that could be later traded for toy prizes. The Sure Bet comparisons were included to assess sensitivity to the numerical comparisons required to assess risk in the Gamble trials. Expected value was equated for Sure Bet and Gamble options at two levels (two and four coins) and for two levels of Risk (coefficients of variation 0.7 and 1.4) [7]. Additionally, a risk preference measure was created using the total proportion of risk trials in which the gamble was selected, allowing risk preference to be used as a covariate in the general linear model of the imaging data analysis.

Results: Similarly to previous imaging studies with adults, we found medial orbitofrontal cortex, dorsolateral PFC, and medial PFC regions to be active while children decided between risky and sure bet options. Posterior parietal cortex (PPC) was activated both during Sure Bet and Gamble trials. Moreover, consistent with previous studies in adult subjects [4], the magnitude of activation in a subregion of PPC was positively correlated with risk preferences across children.

Conclusions: These results concur with findings from adult imaging studies, indicating that neural systems involved with adult decision making are active in children at a young age.

Acknowledgments:
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Will Gamble for Food: Risk Sensitivity with Pigeons in a Token-Reinforcement Paradigm

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Although normative economic theory provides a conceptual basis for understanding how choice options are valued, there is an oft-noted failure of traditional models to account for risky outcomes. In the current behavioral treatment, pigeon subjects were exposed to repeated choices between variable (uncertain) and fixed (certain) numbers of token reinforcers. Each token reinforcer was exchangeable for a discrete amount of access to food. Subjects made 14 choices per day for an average of 24 sessions per condition. The variable-amount payoff was parametrically manipulated across conditions, and the fixed-amount payoff was altered across phases. Results indicate a robust preference for the risky amount both when it paid off equal to and less than that of the fixed payoff. This result is compared to the predictions of a hyperbolic discounting equation with an added amount-sensitivity parameter. This study implicates a paradigm where neural correlates of decision-making can be mapped onto systematic results at the behavioral level of analysis.

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Learning to avoid financial losses: a critical role for the insula.

Stefano Palminteri[1], Virginie Czernecki[1], Carine Karachi[2], Laurent Capelle[2] and Mathias Pessiglione[1]

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Objective:

Reinforcement learning theories aim at explaining how we learn from success and failure. Dopamine has been widely assumed to encode a prediction error signal that drives reward-based learning. In a previous functional MRI study we reported that, while reward prediction error (actual minus expected reward) is represented in the striatum, punishment prediction error (actual minus expected punishment) is represented in the anterior insula, which hence may drive avoidance learning. To test this hypothesis, we completed our fMRI study by subjecting patients with insular damage to the same behavioural task contrasting reward- and punishment-based learning.

Methods

We tested 12 patients with low-grade glioma in the anterior insula, and 12 matched healthy subjects. The task involves subjects choosing between two abstract cues displayed on a computer screen. One pair is associated with winning one euro (reward) and the other with losing one euro (punishment). Associations are probabilistic, such that within the reward pair one cue makes you win more often than the other, whereas within the punishment pair one cue makes you lose more frequently. Subjects are unaware of these contingencies and must learn them through trial and error. Learning curves obtained in the gain and loss conditions were fitted using a standard computational model (Q-learning) that updates the value of the chosen option according to prediction errors.

Results:

Overlap of brain lesions reached a bilateral maximum in the anterior insula that was very close to the region reflecting punishment prediction errors in our fMRI study. Patients were specifically impaired in learning to avoid monetary losses, whereas healthy subjects exhibited no asymmetry between gains and losses. The difference between patients and controls was well accounted for by tuning the loss magnitude in the computational model, so as to get smaller prediction errors.

Conclusions:

We conclude that the insula is causally involved in avoidance learning, and may therefore constitute an opponent system, doing for punishments what the nigro-striatal system does for rewards.

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Saturday, September 26, 2009

Abstracts for Session 4

Emotion and Decision Making

3:05 – 3:25 pm	Nichole Lighthall	Stress modulates sex differences in BOLD response and behavior during decision making	N.R. Lighthall, M. Sakaki, S. Vasunilashorn, S. Somayajula, L. Nga, & M. Mather
3:30 – 3:50 pm	Lasana Harris	Disgust reactions to trustees and dictators modulate punishment decisions in economic games	Lasana Harris, Christine Hosey, Stefanie Molicki, Ernst Fehr, Elizabeth Phelps

Stress Modulates Sex Differences in BOLD Response and Behavior during Decision Making

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Objective: Stress appears to influence decision making under conditions of risk and reward (e.g., Porcelli & Delgado, 2009; Starke et al., 2008). However, evolution may have selected for different behaviors in males and females under stress (Taylor et al., 2000) and recent behavioral studies indicate that stress effects on risk/reward decision making differ for men and women (Lighthall et al., in press; Preston et al., 2007). The present study tested the hypothesis that acute stress would exert different effects on brain activation in men and women during a decision making task involving monetary reward.

Methods: Forty-eight college-age adults (24 female) participated in the study. Half of the participants in each sex group were randomly assigned to the stress condition. Saliva samples were used to measure cortisol responses to stress. Stress was induced using the cold pressor task. Twenty minutes after the cold pressor, participants completed a modified version of the Balloon Analogue Risk Task (BART; Lejuez et al., 2002) during an fMRI. Imaging data was analyzed using the general linear model; the critical contrast being between active decision making and passive button pressing with no chance of gain or loss. All earnings were paid to participants at the end of the session.

Results: Behavior and brain activation was similar for control participants. With stress, however, men exhibited more effective decision making and earned more money during the task whereas stress effects were opposite for women. Stressed males also showed increased BOLD signal in the putamen during decision making but stressed females showed decreased BOLD signal in the same region. Activation in the putamen was associated with BART behavior and total earnings. The difference in putamen activation between stressed and unstressed males was decreased by 26% by controlling for cortisol levels during the BART. Differences between stressed and unstressed females in putamen activation were not altered by controlling for cortisol.

Conclusions: Cold pressor stress induced prior to the balloon decision game increased effectiveness of decision making and activation of the striatum for males; stress effects were opposite for females. Further, our results suggest that cortisol exerts greater influence on striatum activation during decision making in males than females. Striatum is involved in action selection and initiation during decision making and reward learning (Balleine et al., 2007), thus sex differences in stress effects on the striatum may increase sex differences in decision making strategies in a variety of contexts.

Disgust Reactions to Trustees and Dictators Modulate Punishment Decisions in Economic Games

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Previous research demonstrates that in the context of the trust game, punishment decisions are modulated by the perceived responsibility of the trustee for the norm violating behavior and the cost of punishment (de Quervain et al, 2004). We extend these results, showing that the perceived responsibility of the violator for their lot in life as well as the affect, specifically disgust, generated by all parties in the social interaction modulate punishment decisions. We recorded physiological responses across separate samples in the context of second party (trust game) and third party (dictator game) punishment while participants observe fictitious players make fair or unfair decisions before themselves deciding punishment for these social targets. In addition to punishing disgust-inducing social targets more severely in both games, participants in the trust game also punish trustees responsible for their negative life-situation more harshly when trust is violated. Also in the trust game, physiological disgust predicts punishment toward violators that elicit disgust versus another negative emotion. In the dictator game, physiological disgust responses predict punishment amounts when a dictator that elicits disgust behaves unfairly toward a recipient that does not. These findings dovetail with the existing literature, and add to the growing corpus of research on social and affective factors that affect decision-making in economic games. Further research will explore whether the neural mechanisms underlying these decisions diverge.

Sunday, September 27, 2009

Abstracts for Session 5

Temporal Discounting

9:40 – 10:00 am	Bernd Figner	The neural basis of intertemporal choice: Single vs. dual valuation accounts and the role of self-control	B. Figner, D. Knoch, E. J. Johnson, A. R. Krosch, S. H. Lisanby, E. Fehr, & E. U. Weber
10:05 – 10:25 am	William Hedgcock	Neurological correlates of diminished self-control	William Hedgcock, Kathleen Vohs, & Akshay Rao
10:30 – 10:50 am	Shan Luo	Neural and behavioral correlates of value for lone anticipated rewards exhibit steeper delay discounting than do preferences	Shan Luo, George W. Ainslie, Lisa Giragosian, John R. Monterosso

The neural basis of intertemporal choice:
Single vs. dual valuation accounts and the role of self-control

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Objective Three neural accounts of intertemporal choice have been suggested. (1) *Dual-valuation* accounts (McClure et al., 2004, 2007) argue for a steeply discounting β system in (para)limbic brain areas, active only for choices involving immediate rewards, and a more rationally discounting δ system in the dorsolateral prefrontal (DLPFC) and posterior parietal cortex, active for all intertemporal choices. (2) *Single-valuation* accounts (Kable & Glimcher, 2007) assume that valuation in β system brain structures can explain hyperbolic discounting and overweighting of immediate rewards. Both valuation accounts assume that choice follows directly from valuation, i.e, the more highly-valued option is selected. (3) *Self-control* accounts argue that, above and beyond valuation of options, choice is influenced by self-control processes, involving the DLPFC. FMRI studies provide correlational evidence supporting all three accounts (Ballard & Knutson, 2009). Our study was designed to provide causal discriminating evidence between these three accounts, using repetitive transcranial magnetic stimulation (rTMS) to transiently disrupt function of the DLPFC.

Methods 52 participants received one of three rTMS treatments, right DLPFC, left DLPFC, or sham control. Immediately after stimulation, participants made choices between an immediately available sooner smaller (SS) reward and a later larger (LL) reward (*now trials*) and between SS and LL rewards both in the future (*not-now trials*). The relative difference in value of SS and LL varied from 0.5% to 75%. Participants also evaluated the attractiveness of 12 choice options. After rTMS effects had worn off, participants redid the choice and valuation tasks. One randomly selected choice was paid out for real.

Results Compared to sham controls, disruption of left DLPFC function increased SS choices in now trials, especially when the relative magnitude difference of SS and LL rewards was intermediate, i.e., the better choice least obvious, and need for self-control strongest. There were no choice differences between treatment groups after the rTMS effect had worn off. In contrast to choice, there was no effect of rTMS on option valuation. Comparing valuation to choices, we observed two preference reversals: Sham and right DLPFC rTMS groups frequently chose the LL even when the immediately available SS was rated as more attractive. This effect was reversed for the left DLPFC rTMS group.

Conclusions Our results support the self-control account. They implicate the left DLPFC in the modulation of valuation signals when choosing between an immediately available SS and an LL.

Neurological Correlates of Diminished Self-Control

William Hedgcock[1*], Kathleen Vohs[2], and Akshay Rao[2]

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Objective: This study investigated the neurological correlates of diminished self-control that results from regulatory resource depletion. We tested three competing hypotheses. First, depleted subjects might have reduced activity in their entire executive control system. Second, depleted subjects might have reduced activity only in areas associated with implementing control. Finally, depleted subjects might have reduced activity only in areas associated with conflict monitoring.

Methods: The fMRI study had sixteen subjects who participated in the study on two separate occasions. Subjects were randomly assigned to a regulatory task that was either demanding (Demanding) or easy (Easy) in the first session. They then performed the alternate manipulation in the second session.

The Demanding task required subjects to pay attention to a fixation point while ignoring words that were flashed on the screen. The Easy task was identical except that subjects were told they were allowed to look at the words. After performing the regulatory task, subjects performed a choice task.

Results: We measured self-control using response times for the choice task. Subjects chose preferred options faster after performing the Demanding task ($p < 0.025$). This suggests subjects were more impulsive in choices after the Demanding task. A comparison of cerebral activation during the attention control task revealed several significant differences between the Demanding and Easy manipulations. Relative to the Easy condition, brain activity in Demanding condition had widespread increases in activation in the DLPFC (BAs 24/32) and ACC (BA 9). This provides further evidence that our regulatory task manipulated executive control as expected.

Most importantly, we analyzed hemodynamic response during the choice portion of the experiment after subjects performed either the Demanding or Easy task. Relative to choices made after subjects had performed the Easy task, choices made after performing the Demanding task were correlated with decreased activity in the middle frontal gyrus, part of the DLPFC (BA 24).

Conclusions: Prior performance of a demanding regulatory task selectively decreased activation in the middle frontal gyrus. This area has previously been associated with implementing control. This is the first demonstration of a correlation between diminished self-control and reduced DLPFC activity.

Acknowledgements: This study was funded by NSF grant #0647647.

Behavioral and neural evidence of incentive bias for immediate rewards relative to preference-matched delayed rewards

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Several theories of self-control imply that intertemporal decisions can be more farsighted than would be predicted by the incentive value of rewards outside a decision context. We examined this hypothesis using behavior and functional neuroimaging. First, subjects expressed preferences between amounts of money delayed by four months and smaller amounts available that day. This allowed us to establish "indifference pairs"-- immediate and delayed amounts that were equally preferred. Participants subsequently performed a reaction time fMRI task that provided them with distinct opportunities to win each of rewards that comprised the indifference pairs. Anatomical Region of Interest analysis as well as whole-brain analysis indicated greater response recruited by the immediate rewards (relative to the preference matched delayed rewards) in regions previously implicated as sensitive to incentive value using the same task (including bilateral putamen, bilateral anterior insula and midbrain). RT to the target was also faster during the immediate relative to delayed reward trials ($p < .01$), and individual differences in RT between immediate versus delayed reward trials correlated with variance in MR signal in those clusters that responded preferentially to immediate rewards ($r = .33$, $p < .05$). These findings indicate a discrepancy in incentive associated with the immediate versus the preference-matched delayed rewards. This discrepancy may mark the contribution of self-control processes that are recruited during decision-making, but that are absent when rewards are individually anticipated.

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Sunday, September 27, 2009

Abstracts for Session 6

Computational Neuroeconomics

11:25 – 11:45 am	Woo-Young Ahn	Neural correlates of subjective outcome evaluation: Model-based fMRI with hierarchical Bayesian parameter estimation	W-Y. Ahn, A. Krawitz, W. Kim, R. Fukunaga, J.R. Busemeyer & J.W. Brown
11:50 am – 12:10 pm	Kerstin Preuschoff	Risk-minimization through Q-learning of the learning rate	K.Preuschoff & P.Bossaerts
12:15 – 12:35 pm	Debajyoti Ray	A Bayesian model of behaviour in sequential economic games with applications to computational psychiatry	D. Ray, P. R. Montague, & P. Dayan

Neural Correlates of Subjective Outcome Evaluation: Model-based fMRI with hierarchical Bayesian parameter estimation

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Objective: A recent trend in decision neuroscience is to use a mathematical model to estimate cognitive processes and then to estimate neural correlates of time-series extracted from that model. In such an analysis, a critical issue is how to estimate model parameters. Individual participant analysis often leads to noisy estimates while group analysis ignores individual differences. The objectives of this study were to use hierarchical Bayesian parameter estimation to capture both individual differences and group commonalities in a coherent way, and to apply this method to the Iowa Gambling Task (IGT) to reveal neural correlates of decision-making in a complex task.

Methods: Thirty healthy subjects performed the IGT. The Prospect Valence Learning (PVL) model was used to mathematically model their decision-making behavior. The model allows for outcomes to be subjectively evaluated with decreasing sensitivity to absolute payoffs and with gains and losses evaluated differentially. To estimate parameters, we used hierarchical Bayesian analysis (HBA), which can handle individual differences yet pools information across all individuals to obtain more stable and reliable parameter estimates. Model-based time series were generated directly from the posterior distributions of each subject's parameter values and were then correlated against fMRI data. A simulation study was also done to examine whether HBA would perform better than maximum likelihood estimation (MLE) in recovering true parameters.

Behavioral Results: The simulation study confirmed that HBA performed better than MLE in recovering true parameters. The PVL parameter estimates showed that feedback outcomes were evaluated in a nonlinear way.

fMRI results: We found that at the time of decision-making on each trial, activity in ventromedial prefrontal cortex (vmPFC) reflected the computation of value signals. At the time of feedback on each trial, activation of dorsal striatum reflected evaluation of gains and activation of inferior frontal gyrus, insula, locus coeruleus, and anterior cingulate reflected evaluation of losses (i.e. increasing neural activity with increasing absolute magnitude of loss). The shape of the activation for gains and losses for different feedback magnitudes resembled the shape of the subjective utility function generated from the behavioral data.

Conclusion: These results demonstrate that: 1) HBA is useful for model-based fMRI with multiple subjects; 2) learning the advantageous decks in IGT is guided by value signals from vmPFC; and 3) outcomes in the IGT are evaluated subjectively, with subjective outcome signals being passed to subsequent learning processes.

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Risk-minimization through Q-learning of the learning rate

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Background: Most decision-makers are risk-averse and thus try to both increase expected reward and reduce the (prediction) risk associated with their choices. As a result, financial choices between risky gambles are based on a trade-off between risk and reward and changes in (prediction) risk significantly affect how we learn about rewards. We have previously shown how simple Rescorla-Wagner and TD-learning rules can be adjusted to include a risk-sensitive learning rate (Preuschoff & Bossaerts, 2007). In this model the optimal learning rate depends on how much correlation (covariance) there is between predictions and the immediately preceding prediction error.

Objective: We build on our previous model to try and find the optimal learning rate to minimize prediction risk.

Methods: Here, we borrow ideas from Q-learning to translate risk-sensitive reward-learning into learning an action-value function that minimizes prediction risk using past reward prediction errors. The ensuing optimization problem converges under the same conditions as standard Q-learning algorithms.

Results: Using the inverse prediction risk as a reward and the reward-learning rate as an action, we show how the resulting policy can be used to adjust the (reward-) learning rate. Evidence is discussed that suggests that the dopaminergic system, insula and ACC in the (human and nonhuman) primate brain support a risk-minimizing algorithm in addition to risk-sensitive reward learning (e.g., Behrens et al, 2007).

Conclusions: Together with the previous model this can be used to incorporate the trade-off between expected reward and risk by adjusting the learning rate in reward-based learning. The model can be generalized to include risk-neutral as well as risk-seeking decision makers. It essentially extracts information about the origin of uncertainty (e.g., risk vs. ambiguity) to decide on how much weight to put on more recent prediction errors compared to those that occurred many time steps ago.

A Bayesian model of behaviour in sequential economic games with applications to computational psychiatry.

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As for all social species, the success or failure of many of our actions depend critically on what other, independent, decision-makers do. Achieving personally or socially efficient outcomes therefore requires us to build, maintain, update and use sophisticated models of these other entities. The fields of experimental and behavioural economics include a rich range of empirical approaches to studying such interactive decision-making, and have revealed the importance of social utility constructs such as envy and guilt that depend on the relationship between multiple choosers. Experiments into the neural bases of such decisions suggest the involvement of areas of the brain that are becoming associated with the ‘theory of mind’, i.e., the models we build of others.

In order to gain a sharper picture of the computations and calculations underlying such choices, we are marrying the sort of reinforcement learning that has been highly successful as a model of approximately normative individual or single-agent decision-making with economic ideas about interactivity in the context of games [1]. Our subjects are defined by two characteristics, one is their *types*, in our case the parameters of their individual social utility functions. As is common, we assume that the subjects know their own types, but not those of the others; there is therefore incomplete information. Thus the theories of mind they need to build and which will influence future interactions are exactly about the types of the other subjects. This leads to the subjects’ second characteristic, namely the number of levels or orders of belief they entertain about the other subjects. We also assume that this is not necessarily known.

We use approximate inference methods to solve the resulting partially observable Markov game (POMG), and look at the qualitative classes of behaviour that emerge from dyads with different characteristics. Behaviours such as probing arise in multi-round games, as subjects attempt to learn about, and take advantage of, each others’ types. Our models thus capture observed interactions, and also be used to generate regressors for fMRI data. Furthermore we can classify player types through their inferred parameters, potentially differentiating between Normal subjects and subjects with social disorders such as Borderline Personality Disorder.

We apply our model to classify subjects in a multi-round Investor-Trustee game [2], as well as population of subjects with Borderline Personality Disorder [3]. Observed phenomena such as the build-up and break-down of cooperation over the course of the multi-round game emerge in our modeled interactions; the relative importance of different parameters for different players also becomes starkly apparent.

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Sunday, September 27, 2009

Abstracts for Session 7

Uncertainty

1:45 – 2:05 pm	Rhanor Gillette	Value, risk, reward and decision in neuronal circuitry of a simple model animal	Rhanor Gillette, Vanessa Nobo, Keiko Hirayama & Jeffrey Brown
2:10 – 2:30 pm	Rick Jenison	Uncertainty coding by single neurons in the human amygdala	Rick L. Jenison, Hiroyuki Oya, & Matthew A. Howard III
2:35 – 2:55 pm	Colin Camerer	The boggled mind: Choice overload and neural correlates of choice set size	Elena Reutskaja, Axel Lindner, Rosemarie Nagel, Richard A. Andersen, & Colin F. Camerer

Value, Risk, Reward and Decision in Neuronal Circuitry of a Simple Model Animal.

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The neuronal computations by which animals conform to predictions of economic theory are keystones of general models of brain and behavior. Mammalian studies in economics-based choice combine classical ethological approaches with contemporary neurophysiological methods to study the neural bases of Value, Risk, Reward and Decision. Such “top-down” studies monitor activities of single neurons or populations to infer the characters of decision at a finer level of circuitry. Invertebrate studies of very accessible nervous systems can provide plausibly detailed models for the general relationships generated in mammalian studies. “Bottom-up” studies of the simpler model systems are elucidating in detail circuitry underlying cost-benefit decision-making. Will such observations will be of more than marginal interest to mammalian experimenters? We will explore simple and general neuronal models of cost-benefit decision applicable across the broad spectrum of animal behavior.

Exploratory foraging and prey-tracking in the generalist, predatory sea-slug *Pleurobranchaea californica* entail decisions among approach, avoidance, attack and escape (www.life.uiuc.edu/slugcity). These decisions integrate hunger, taste, pain and memory of experience in terms of value, risk and reward. Combined electrophysiological and behavioral observations show that expression of decision is carried out by interactions among well-characterized neuronal networks for feeding, turning, locomotion and escape swimming.

We summarize neuronal mechanisms of foraging decisions based on interactions among well characterized neuronal circuits for feeding, locomotion, orienting and avoidance turning, and escape. Integral roles for serotonin, and its neuronal circuit substrates, in arousal, appetite, stimulus valuation, risk assessment and reward are presented for comparison and contrast with the roles of serotonin and peptides in vertebrates.

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Uncertainty Coding by Single Neurons in the Human Amygdala

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Objective: Uncertainty about some potential outcome can be the result of either known probabilities (risk) or unknown probabilities as a consequence of missing information (ambiguity). The amygdala has been implicated in decision making under conditions of uncertainty, but it is unclear what computational role the amygdala plays in this process. In terms of structure and function, the amygdala serves as a central hub of information passing from several cortical and thalamic structures making the amygdala an ideal locus for the coding of components of expected utility. We tested the hypothesis that single-unit activity in the amygdala codes a graded measure of aversion to uncertain gambles.

Methods: We investigated the neural basis of uncertainty by recording single-unit activity in the human amygdala while patient-participants chose between the opportunity to gamble or accept a sure win under differing conditions of ambiguity and risk. These studies were carried out in patients undergoing diagnosis and, later, surgical treatment for medically intractable epilepsy. Participant-patients undergo implantation of intracranial electrodes for periods of up to two weeks, after which electrodes are surgically removed and the seizure focus removed. Participant-patients are awake and alert during recording sessions. We recorded from microcontacts on an electrode implanted directly in the amygdala nuclei for which we have high resolution MRI to precisely identify where the microcontact is positioned. We modeled the neural spiking activity using a generalized linear model (Poisson-GLM) that integrates a nonlinear stochastic choice model for ambiguous and risky gambles. Parameters characterizing ambiguity aversion in the choice model were first estimated from the behavioral data, and then introduced as covariates in the Poisson-GLM model.

Results: Single-unit activity in the amygdala reliably codes the expected utility of the gamble with respect to the sure win. Spike train prediction by the model depended significantly on the behavioral degree of ambiguity aversion.

Conclusions: These results suggest that precisely localized amygdala neurons code a form of expected utility within the temporally-rich spiking activity that reflects a graded response to degrees of economic ambiguity.

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The boggled mind: Choice overload and neural correlates of choice set size

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<u>Objective:</u> Many psychology experiments suggest that people feel overwhelmed by the number of available consumer choices. We explored neural activity during choices from small, medium and large choice sets of size S. The guiding hypothesis is that costs of choosing are increasing with S and outweigh the benefits at some point. The net benefit of choosing would thus be an inverted-U function of S, contrary to economic theory, which typically assumes the value of a choice set to be the value of its best item.

<u>Methods:</u> N=19 subjects participated in fMRI. They first rated 52 landscape pictures in each of six categories (e.g., beaches, dunes, etc.). The subject-specific liking ratings were used to create choice sets with S=6, 12 or 24 items in which there was a clear favorite (CF), no clear favorite (NF) or forced-choice sets (FO), a NF set in which either the first- or second-ranked item was highlighted and had to be chosen. Subjects had to choose from eight sets in each of the 3x3 conditions while brain activity was monitored using fMRI.

<u>Results:</u> GLM regressors of/for fMRI activity during choice were normalized linear functions of choice set size S, and inverted quadratic functions. Areas with activity increasing with S include visual and premotor areas. We interpret these as reflecting the visual and motor demands required when choosing from larger choice sets. Activity inversely increasing in the quadratic of S (i.e., highest for the 12-item set) was mapped in the ventral striatum, the anterior cingulate, dorsolateral prefrontal-, orbitofrontal- and parietal- cortex. We interpret these areas, often responsive in value encoding in studies with small numbers of choices, as encoding a net choice set value which was actually lower for the largest choice set— a neural signature of choice overload. Importantly, activity in the latter areas was increasing with S, not exhibiting an inverted-U, during the forced choice condition (when choosing costs are eliminated).

<u>Conclusions:</u> Activity in valuation areas in response to presentation of choice sets was largest for a medium number of choices and lower for ((both 'too little' and)) 'too many' choices. This study shows how fMRI signals may ((help to)) decode the value of choice *sets*, and those values may fall with S, implicitly adding up the costs and benefits of choosing.

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