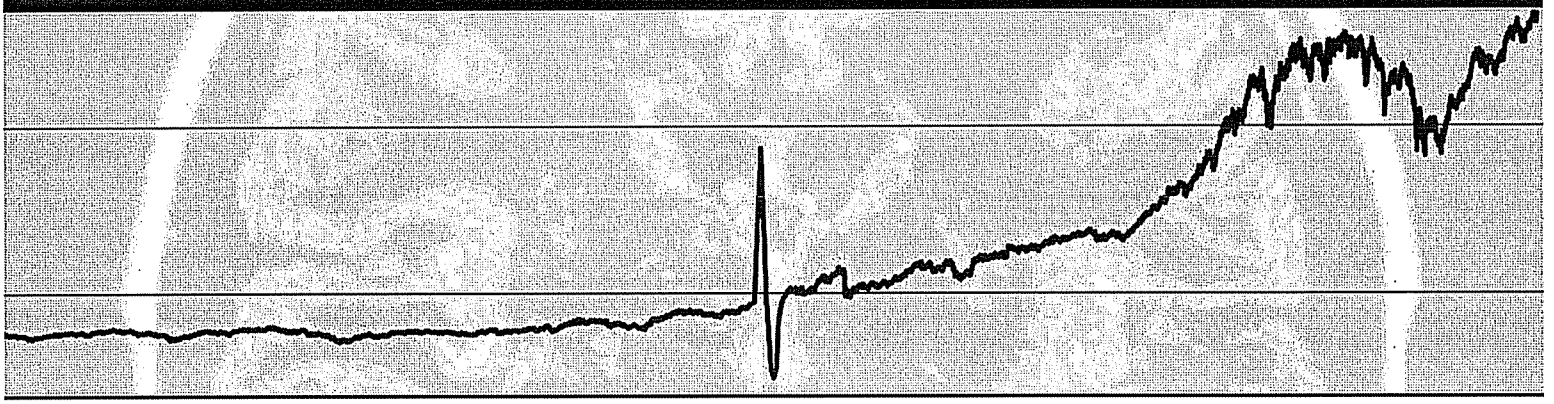
SOCIETY FOR NEUROECONOMICS

MEETING PROGRAM



4th ANNUAL MEETING

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PARK CITY, U.T.

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SEPTEMBER 07-10 2006

SOCIETY FOR NEUROECONOMICS

Schedule of Events for Neuroeconomics 2006, Park City, UT

Thursday, September 7, 2006

1:30 - 5:00 pm	Workshops in the Foundations of Neuroeconomics	White Pine Parlor I & II

The following two workshops will occur simultaneously, and you may choose which one you would like to attend

	Workshop I: Neuroscience for Economists	Workshop II: Economics for Neuroscientists
1:30 – 3:00 pm	The Other Neuroeconomics: Single Neuron Studies in Awake Behaving Primates Michael Platt—Duke University	Game Theory for Neuroeconomics David Levine—Washington Univ. St. Louis
3:00 – 3:30 pm	Break	
3:30 – 5:00 pm	Brain Anatomy Paul Glimcher—New York University	Experimental Methods in Game Theory Teck-Hua Ho—UC Berkeley
6:00 pm	Reception	Doc's at the Gondola
7:00 pm	Buffet Dinner	Kokopelli—Parlor II

Friday, September 8, 2006

8:00 – 9:00 am	Continental Breakfast		White Pine Lobby
8:45 – 9:00 am	Colin Camerer	Welcome & Opening Remarks	White Pine Ballroom
	Loss Aversion		White Pine Ballroom
9:00 – 9:30 am	Craig Fox	Losses loom larger than gains in the brain: Neural loss aversion predicts behavioral loss aversion	UCLA
9:35 – 10:05 am	Laurie Santos	Do capuchin monkeys (Cebus paella) exhibit the endowment effect?	Yale University
10:10 – 10:40 am	Hyojung Seo	Neuronal signals related to gains, losses, and utilities in the medial frontal cortex of monkeys	University of Rochester
10:45 – 12:15 am	Poster Session I		Arrowhead I & II
12:30 – 1:30 pm	Lunch		The Canyons Pavilion
1:45 – 3:15 pm	Poster Session II		Arrowhead I & II
	Risk		White Pine Ballroom
3:30 – 4:00 pm	Elke Weber	Neural substrates of risky decision making	Columbia University
4:05 – 4:35 pm	Kerstin Preuschoff	Human insula activation in a monetary gambling task reflects uncertainty prediction errors as well as uncertainty levels	California Institute of Technology
	Prospect Theory		White Pine Ballroom
4:40-5:10 pm	Ming Hsu	Probability weighting function in the brain	California Institute of Technology
5:15 – 5:45 pm	Greg Berns	A neurobiological derivation of prospect theory and experimental evidence over losses	Emory University
7:00 pm	Dinner		The Forum

Saturday, September 9, 2006

8:30 – 10:00 am	Continental Breakfast		White Pine Lobby
	Time		White Pine Ballroom

10:00 – 10:30 am	Chess Stetson	Reward timing is a special case of event timing: Evidence from the basal ganglia	University of Texas
10:35 – 11:05 am	Kenway Louie	Temporal discounting activity in monkey parietal neurons during intertemporal choice	New York University
11:10 – 11:40 am	Ching-Hung Lin	Medial prefrontal activities represent immediate monetary outcomes in the Soochow Gambling Task: A Near-infrared Ray combined EEG study	National Yang-Ming University
11:45 – 12:15 am	Thomas Campbell	The neurobiology of intertemporal choice	University of Oxford
12:20 – 1:20 pm	Lunch		The Canyons Pavilion
	Marketing		White Pine Ballroom
1:30 – 2:00 pm	Vasily Klucharev	Brain mechanisms of persuasion: fMRI study of persuasive nature of advertising	Erasmus University, Radboud University, Nijmegen
2:05 – 2:35 pm	Brian Knutson	Neural predictors of purchases	Stanford University
	Learning		White Pine Ballroom
2:40 – 3:10 pm	Paul Phillips	Subsecond dopamine release during economic decision making in rodents	University of Washington
3:15 – 3:45 pm	Daniela Schiller	Learning by doing—Actions reinforced by fear termination	New York University

Evening free, dinner on your own

Sunday, September 10, 2006

8:00 – 9:00 am	Continental Breakfast		White Pine Lobby
	Choice		Arrowhead
9:00 – 9:30 am	Camillo Padoa-Schioppa	Neurons in orbitofrontal cortex encode economic value independently of the "menu"	Harvard Medical School
9:35 – 10:05 am	Adam Kepecs	Rats under uncertainty: Orbitofrontal neurons support updating of decision strategy	Cold Spring Harbor Laboratory
10:10 – 10:40 am	Ryan Jessup	Decision field theory as a bridge between neural models and complex decision making behavior	Indiana University
10:40 – 11:15 am	Break/Checkout		
	Sociality		Arrowhead
11:15 – 11:45 am	Paul Zak	An fMRI study of trust with exogenous oxytocin infusion	Claremont Graduate University
11:50 – 12:20 pm	Frank Krueger	The neural basis of economic decision-making in two-players' reciprocal trust games	NIH/NINDS
12:25 – 12:55 pm	William Harbaugh	The neural basis of charitable giving	University of Oregon

Poster Sessions

Session I, Friday 10:45 – 12:15	
Authors	**Title**
Meghana Bhatt	A Neural Network Model of Product Evaluation and Marketing
Bickel, W.; Lindquist, D.; Pitcock, J.; Yi, R.; Gatchalian, K.; Landes, R.; Kowal, B.	Smokers and Non-smokers in a Delay Discounting Task: Functional Activity
Shoshanna Campbell, Jean-Charles Chebat, Maurice Ptito	Lighting Up! The Neurophysiological effects of anti-tobacco advertising on smokers and non-smokers
Yao-Chu Chiu, Ching-Hung Lin, Shuyeu Lin, Jong-Tsun Huang	Reexamining the Effect of Long-term Outcome and Gain-loss Frequency: From Uncertainty to Certainty
Bernhard Connemann, Christoph Bux, Nenad Vasic, Christian Wolf, Georg Gron, Manfred Spitzer	Discounting of Delayed Monetary Reward in Major Depressive Disorder (MDD)
Jeffrey C. Cooper, Jamil Bhanji, & Brian Knutson	Incentive value or incentive salience? Comparing two accounts of nucleus accumbens function
E. J. DeWitt, M. Dean, P. W. Glimcher	Reinforcement learning: Studying the development of preferences with a known optimal policy for learning
John Dickhaut, Ovidiu Lungu, Baohua Xin and Aldo Rustichini	A mechanism for human choice
Brent A Field, Cara L Buck, Samuel M McClure, Daniel Kahneman, Jonathan D Cohen	Influence of attention on brain responses to appetitive and aversive stimuli
Peter H. Huang	Law and Human Flourishing: Affective Neuroscience, Happiness, and Paternalism
Kaisa Hytonen, Oliver Langner, Vasily Klucharev, Ale Smidts, Ivan Toni, Jens Schwarzbach	Decision or response preparation? Separating decision making from motor actions
Thomas Jhou	Working more for less: a review of seemingly paradoxical work schedules in humans and animals
Joseph W. Kable and Paul W. Glimcher	Time consistency in temporal discounting: Behavioral evidence and neural mechanisms
P. Kenning, H. Plassmann, C. Backhaus, D. Ahlert	Neural Foundations of People-System Relationships
Seungyeon Kim, Jaeseung Jeong	Neural correlates of elation and disappointment in decision-making
Ching-Hung Lin, Yao-Chu Chiu, Chou-Ming Cheng, Jen-Chuen Hsieh	What is the real function of medial frontal cortex under a complete uncertainty? An fMRI study of the Iowa Gambling Task
Soyoun Kim, Jaewon Hwang, Daeyeol Lee	Computation of discounted utilities in the primate prefrontal cortex

Session II, Friday 1:45 – 3:15	
Authors	**Title**
Jeffrey Klein, Rob Deaner and Michael Platt	Parietal neurons encode social and fluid value in orienting decisions
Camelia M. Kuhnen, Brian Knutson	Neural Predictors of Overconfidence in Financial Decision-Making
Venkat Lakshminarayanan, M. Keith Chen, Laurie R. Santos	The Evolution of Decision-Making Under Uncertainty: Framing Effects in Non-Human Primates
Ching-Hung Lin, Yao-Chu Chiu, Yu-Kai Lin , Jen-Chuen Hsieh	Event-related skin conductance in response to immediate monetary gain-loss in the Soochow Gambling Task
Arwen B. Long, Sheila Roberts, Michael L. Platt	Rapid Phenylalanine and Tyrosine Depletion Modulates Macaque Decision-Making
Anup Malani, Daniel Houser	Expectations Mediate Objective Physiological Placebo Effects
Dan Ariely, Jonathan D. Cohen, Keith M. Ericson, David I. Laibson, George Loewenstein, Samuel McClure, Drazen Prelec	Implementing self-control
Benjamin Hayden and Michael Platt	Risk preference in monkeys depends on behavioral context
Robb B. Rutledge, Brian Lau, Stephanie C. Lazzaro, Catherine E. Myers, Mark A. Gluck,Paul W. Glimcher	Parkinson's disease affects reinforcement learning in a dynamic environment
Patrick Simen, Philip Holmes and Jonathan D. Cohen	Melioration through Adaptive Threshold Adjustement in a Drift Diffusion Model of Decision Making
P. Sokol-Hessner, M. Hsu, M. Delgado, C. Camerer, E.A. Phelps	Reappraising Loss Aversion: Manipulating Choices with Emotion Regulation Strategies
Dharol Tankersley, C. Jill Stowe, Scott A. Huettel	Altruism & the Perception of Agency in the Superior Temporal Sulcus
KW Watson and M.L. Platt	Acute tryptophan depletion alters valuation of both social and reproductive images
Martijn Willemson, Ulf Bockenholt and Eric J. Johnson	Three Models of Loss Aversion with Implications for Neuroeconomics
Yao-Chu Chiu, Shuyeu Lin, Shaoling Wang, Ching-Hung Lin & Jong-Tsun Huang	Is Isolation Effect in Prospect Theory A Rule or An Exception?
John Dickhaut, Greg Waymire, Kevin McCabe	Uncovering the Neuronal Bases of Human Behavior in Economic Institutions

Thursday, September 7, 2006

Workshop I: Neuroscience for Economists

Part 1

1:30 -3:00 pm **Michael Platt: The Other Neuroeconomics: Single Neuron Studies in Awake Behaving Primates**

While the majority of studies in Neuroeconomics have employed functional magnetic resonance imaging, a large number of studies have analyzed the activity of single neurons in the brains of non-human primates making decisions. Single neuron studies offer a number of critical advantages over fMRI like higher temporal and spatial resolution and a higher signal-to-noise ratio. Despite these advantages, many neuroeconomists remain unfamiliar with this technique. In this worshop the basic methodology will be presented along with practical details that should help non-physiologists become better consumers of single unit papers. The advantages, disadvantages, and constraints of this methodology will be the central focus of the workshop.

Part 2

3:30 – 5:00 pm **Paul Glimcher: Brain Anatomy**

The focus of this workshop will be to help participants to develop a greater familiarity with basic brain anatomy. The workshop will begin with a discussion of terminology and then proceed through a lecture on the main divisions of the mammalian brain and the three-dimensional review of the structures that make up these main divisions. The workshop will conclude with a guided dissection of actual sheep brains by the participants.

Workshop II: Economics for Neuroscientists

Part 1

1:30 -3:00 pm **David Levine: Game Theory for Neuroeconomics**

I'll discuss behavioral anomalies in basic game theory. Most anomalies have to do with preferences not equilibrium. I'll look at experiments on the centipede game and ultimatum bargaining and explain that the problem lies with individual decision making not the equilibrium theory. I'll emphasize that quantitatively the size of anomalies is not big, and point out some examples, including voter participation and competitive equilibrium, where existing theory works well. Then I'll point out the behavioral anomalies: interpersonal preferences and the degree of non-linearity in revealed preference. I'll discuss the Rabin Paradox, the Allais Paradox and the token donation paradox.

Recommended Reading: Camerer (2004)* from the Handbook of Experimental Economics introductory chapter

Part 2

3:30 – 5:00 pm **Teck-Hua Ho: Experimental Methods in Game Theory**

Equilibrium theories in games are general and produce precise predictions, but they rely on strong assumptions of decision makers. In this talk, we discuss three streams of experiments on simple games to show how the equilibrium theories fail and how equally precise and general models can be developed to address these inadequacies. These new models generalize decision maker's preference to capture social preferences toward outcomes of others and allow decision makers to encounter limits on the depth of strategic thinking as well as adjust their behavior over time by learning from feedback.

Friday, September 8, 2006

Session I
Loss Aversion

9:00 – 9:30 am	Craig Fox	Losses loom larger than gains in the brain: Neural loss aversion predicts behavioral loss aversion	UCLA
9:35 – 10:05 am	Laurie Santos	Do capuchin monkeys (Cebus paella) exhibit the endowment effect?	Yale University
10:10 – 10:40 am	Hyojung Seo	Neuronal signals related to gains, losses, and utilities in the medial frontal cortex of monkeys	University of Rochester

Title: Losses loom larger than gains in the brain: Neural loss aversion predicts behavioral loss aversion

Authors: Craig Fox, Sabrina Tom, Christopher Trepel, and Russell A. Poldrack

Institution: UCLA Anderson School and Department of Psychology

Email of presenting author: cfox@anderson.ucla.edu

Web address URL for a paper (if available):

Abstract text (fill no more than this page)

One of the most robust phenomena to emerge in studies of decision behavior in humans and other animals is loss aversion, the tendency to exhibit greater sensitivity to losses than to equivalent sized gains.

Using functional magnetic resonance imaging, we examined brain activity while individuals decided whether to accept or reject gambles that each offered a 50% chance to gain between $10 to $40 and a 50% chance to lose between $5 to $20. None of these gambles were resolved during the task, so that activity reflected decisions rather than anticipation or experience of monetary gains or losses. Neural activity in a broad network of regions (including midbrain dopaminergic regions and their limbic and cortical targets) showed increased activity as the size of the potential gain increased, and decreased activity as the size of the potential loss increased. This demonstrates that brain responses to losses do not reflect engagement of distinct emotional brain systems but rather decreasing activity in some of the same regions that code for gains. Moreover, activity in these regions exhibited neural loss-aversion in which activity was more sensitive to losses and to gains. Finally, individual differences in behavioral loss aversion were predicted by a measure of neural loss aversion in a number of regions including the striatum and anterior cingulate. These results provide the first neuroscientific evidence that risk aversion in the context of mixed gain-loss gambles is driven by greater sensitivity to losses than gains.

Title: Do Capuchin Monkeys (Cebus apella) exhibit the endowment effect?

Authors: Drew Marticorena, Venkat Lakshminarayanan, Laurie Santos

Institution: Yale University

Email of presenting author: drew.marticorena@yale.edu

Web address URL for a paper (if available):

Abstract text (fill no more than this page)

A number of classic studies have demonstrated that human subjects display an "endowment effect." — hey place a higher value on a good that they own versus an equally-priced good that is not in their possession. Here, we present evidence that the endowment effect is also present in the choices of an ancestrally-related new-world primate, the capuchin monkey (Cebus apella). We presented capuchin monkey subjects with a token trading task in which they could exchange a fiat currency for foods. For each subject, we identified a pair of goods (e.g. fruit disc and a cereal cube) between which they were indifferent. Given a limited budget and two trading options, capuchins purchase equal quantities of both goods. However, subjects were generally unwilling to trade away fruit-disc currency (no longer fiat) in their possession in order to obtain the cereal-chunks (or vice versa). In contrast, all subjects were willing to exchange these goods for a highly-desirable candy. These data suggest that a common evolutionary ancestor may have provided both humans and capuchins with the psychological prerequisites for the endowment effect. Additionally, the presence of these anomalous choices in capuchins indicate that these biased preferences do not rely on uniquely-human cognition, and rather owe to more architecturally primitive and evolutionarily ancient systems.

Title: Neuronal signals related to gains, losses and utilities in the medial frontal cortex of monkeys

Authors: Hyojung Seo, Daeyeol Lee

Institution: University of Rochester, Yale University School of Medicine

Email of presenting author: hseo@cvs.rochester.edu

Web address URL for a paper (if available):

Abstract text (fill no more than this page)

To choose an action among multiple alternatives, potential gains and losses must be taken into consideration to derive a measure of utility for each action. However, the neural mechanisms responsible for computing utilities from gains and losses are largely unknown. In this study, we recorded neural activity from the supplementary eye field (SEF) and dorsal anterior cingulate cortex (ACCd) in rhesus monkeys performing a decision-making task in which the outcome of a choice could be negative (loss), neutral, or positive (gain).

Throughout the experiment, the computer screen displayed a variable number of red disks (asset), and when the animal earned 6 disks, they were exchanged with 6 drops of juice. At the onset of the next trial, 2, 3, or 4 disks were provided as an initial balance for the subsequent trials. At the end of each trial, the number of disks increased, decreased, or remained unchanged, corresponding to positive, negative, and neutral outcomes, respectively. The animal began each trial by fixating a square at the center of the screen, and two peripheral targets were presented along the horizontal meridian. When the central square was extinguished after a 0.5 s-delay period, the animal was required to shift its gaze towards one of the two targets. After a 0.5-s hold period, the outcome of the animal's choice was revealed by the color of a feedback ring presented around the chosen target. Choosing one of the targets ("safe" target) led to a positive or neutral outcome, whereas the other target ("risky" target) led to a positive or negative outcome. The animal obtained the positive outcome only when it selected the same target as the computer, which was programmed to simulate an opponent in a mixed-strategy zero-sum game. Accordingly, the optimal strategy was to choose the safe target with a 2/3 probability. The positions of the safe and risky targets were switched unpredictably after a minimum of 40 trials.

The behavioral data showed that the animal's choice was systematically affected by the outcome of its previous choice. Single-unit activity was recorded from the SEF and ACCd, and, for each neuron, the spike counts during the 0.5-s interval after the feedback onset was analyzed with a 2-way ANOVA (asset x outcome). Activity was more frequently influenced by gains than by losses, and this was true in both cortical areas (86% vs. 46% in SEF; 69% vs. 28% in ACCd). Furthermore, activity of some neurons in SEF (30%) and ACCd (17%) was antagonistically modulated by gains and losses. These results suggest an important role of the medial frontal cortex in calculating utilities based on gains and losses.

Poster Session I Friday 10:45 – 12:15	
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Bickel, W.; Lindquist, D.; Pitcock, J.; Yi, R.; Gatchalian, K.; Landes, R.; Kowal, B.	Smokers and Non-smokers in a Delay Discounting Task: Functional Activity
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Soyoun Kim, Jaewon Hwang, Daeyeol Lee	Computation of discounted utilities in the primate prefrontal cortex

Title: A Neural Network Model of Product Evaluation and Marketing

Authors: Meghana Bhatt

Institution: Caltech

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Web address URL for a paper (if available):

Abstract text (fill no more than this page)

Current economic models of advertising tend to focus on advertisements as purely informational or as signals of quality (money burning). Neither of these explanations explain the richness or importance of the advertising industry. This paper posits and alternative mechanism for advertisements to influence the evaluation of a product that uses formal models of pattern recognition and associative memory. The model provides formal explanations for the relevance of trivial attributes to advertising effectiveness as well as their influence on choice. It provides a framework that should eventually be able to help predict the success and failure of brand extensions. The model provides a single formal theory that unifies ideas about branding, interesting marketing phenomena including part-cue inhibition, the importance of packaging for generic products, and categorization.

Title: Smokers and Non-smokers in a Delay Discounting Task: Functional Activity

Authors: Bickel, W.[1]; Lindquist, D.[2]; Pitcock, J.[1]; Yi, R.[1]; Gatchalian, K.[1]; Landes, R.[3]; Kowal, B.[1]

Institution: 1. Psychiatry, UAMS, Little Rock, AR, USA; 2. Radiology, UAMS, Little Rock, AR, USA; 3. Biostatistics, UAMS, Little Rock, AR, USA

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Web address URL for a paper (if available):

Abstract text (fill no more than this page)

Smokers are considered impulsive in part because they discount the future more than non-smokers. Prior studies have demonstrated a relationship between decision making and the prefrontal cortex and the anterior cingulated. Thus, we hypothesized that smokers engaged in a discounting task would exhibit decreased cortical and cingulate activity compared with non-smokers in an event-related fMRI study. Thirty subjects were enrolled in this study and 18 completed (9 smokers), which was approved by the institutional review board. During the scan, subjects made a choice between receiving $x now (4 values of X) and $100 later (4 later times). At the end of the session, one of the questions was randomly selected and the subject received payment according to their choice for that question. A gradient echo EPI sequence was used to collect T2* data on a 1.5T GE Echospeed LX 9.1 system. Imaging data for each subject was corrected for motion, normalized into a standardized Talairach template and spatially smoothed using SPM2. An event-related analysis was done using the General Linear Model in SPM2 with signal changes modeled as delta functions located at stimulus presentation onsets and convolved with a canonical hemodynamic response function. A t statistical map was generated for each subject, which was used in a second level analysis to contrast smokers and non-smokers. The results showed statistically significant increases in activity in medial BA 32, left parietal lobe (BA40), left caudate, right cerebrum (BA31), and right inferior frontal gyrus (BA45) in non-smokers relative to smokers. The activated areas are known to be involved in reasoning or decision-making and impulse control, particularly the frontal cortex and cingulate. These findings demonstrate that smokers use these regions less than non-smokers and are consistent with the greater discounting associated with cigarette smokers.

Title: Lighting Up ! The Neurophysiological effects of anti-tobacco advertising on smokers and non-smokers

Authors: Shoshanna Campbell[1], Jean-Charles Chebat[1], Maurice Ptito[2]

Institution: Hec Montreal [1], University of Montréal Department of Visual Neurosciences [2]

Email of presenting author: Shoshannacampbell@sympatico.ca

Web address URL for a paper (if available):

Abstract text (fill no more than this page)

Introduction: Are the anti-tobacco health warnings (HW) on cigarette packages effective? And what are the neurophysiological effects of such HW? Since 2000, federal legislation in Canada obliges tobacco manufacturers to feature shocking, graphic HW - a photo of a diseased lung, for example, along with a blunt message on the risks of smoking - which must cover half of the package surface. Although there has been a general decline in smoking, the rate of young female smokers remains constant at 31%, and female smokers are the most likely to be lifetime smokers. Previous studies suggest that the HW, which are a significant part of the Canadian government's anti-tobacco marketing campaign, have lost much of their effectiveness. Until now, the impact of these HW on the brain have never been assessed.

Objective: Using fMRI technology, this study seeks to determine which brain structures are affected by such HW, and whether brain activations differ between smoking and non-smoking females.

Methods: fMRI data was collected from healthy female subjects (N=33) between the ages of 18-35, separated into two cohorts of 15 smokers and 18 non-smokers. 12 of the 16 HW created by the Canadian government and currently in circulation were chosen (Neg; N=12). These were contrasted with 24 pictures chosen from the International Affective Picture System (IAPS). 12 with a neutral (Neu; N=12) and 12 with a positive (Pos; N=12) valence rating. As well, the HW were separated into their text-only and image-only components. A block design was used for the picture presentation. Each block consisted of 4 pictures - all negative, neutral, positive, text only, or image only - whose sequence is fixed. Each presentation employs 15 different blocks for a total of 60 pictures (N=60). Each picture was shown for a duration of 12 seconds without interval. The precise sequence of 15 blocks which comprises each presentation was determined by a computer generated randomizing function.

Results: The results of our study show that there are significant brain activation differences between smokers and non-smokers when reacting to the HW. We found increased activations in the right dorsolateral prefrontal cortex, anterior cingulate gyrus, and the medial prefrontal cortex of non-smoking subjects. Significant deactivation in the same structures was also observed when a smoking subject was presented with the HW.

Conclusion: Our results suggest that smokers are now immune to the HW on cigarette packages whereas non-smokers are still affected by these advertisements. The application of neuroscience to investigate the impact of anti-tobacco advertising is a powerful tool to facilitate the creation of more efficacious anti-tobacco marketing campaigns in Canada and throughout North America, whether designed to counter smoking initiation or aid in smoking cessation.

This research project is sponsored by the Canadian Tobacco Control Initiative (CTCRI), reference # 016742.

Title: Reexamining the Effect of Long-term Outcome and Gain-loss Frequency: From Uncertainty to Certainty

Authors: [1]Yao-Chu Chiu, [2]Ching-Hung Lin, Shuyeu Lin, [3]Jong-Tsun Huang

Institution: [1]Department of Psychology, Soochow University, Taipei, [2]Institute of Neuroscience, National Yang-Ming University, Taipei, [3]China Medical University, Taichung, Taiwan.

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Web address URL for a paper (if available):

Abstract text (fill no more than this page)

The studies in behavioral decision making and affective neuroscience have pointed out that normal decision makers are often myopic to the long-term outcome. On the contrary, Damasio (1994) proposed the Somatic Marker Hypothesis and then conducted the Iowa Gambling Task (IGT) to demonstrate that while ventromedial prefrontal patients are short-sighted to the long-term outcome, normal decision makers are foresighted. To reconcile this marked discrepancy, we modified the gambling task (Soochow Gambling Task, SGT) to correct the unsatisfactory confoundings in IGT and differentiate the relative contribution between long-term outcome and gain-loss frequency (Chiu et al., 2005). In SGT, normal subjects would stick to the influence of immediate gain-loss frequency without shifting to the long-term outcome dimension throughout the whole session of the experiment. The result showed that immediate reinforcement will override long-term outcome, which is contrary to the prediction of Somatic Marker Hypothesis. However, the data are consistent with the view of the behavioral and affective decision literature that normal subjects are often myopic or short-sighted in decision making. To further elucidate the reasons that may underlie this result, we conducted two types of experiments by extending the standard protocol of decks for card turning to one-hundred more trials. Under the uncertainty condition, no information concerning the internal structure of four decks was provided. Subjects (n=24) were supposed uncertain of the gamble structure of four decks. Two-hundred trials were administered and the result showed that subjects prefer to choose decks with high-frequency gain but lower long-term outcome, even under the extended session of the extra one-hundred more trials. The normal subjects seem to be myopic or short-sighted to long-term outcome in the first and second hundred trials. No "hunch" could ever be achieved in the extended session. For the second type of experiment, an uncertainty-certainty shift condition was administered. The subjects (n=24) were first run for the first 100 trials under an uncertainty condition and then shifted to the second 100 trials with notification of gamble structure (or technically, a risk condition). Subjects are myopic to the long-term outcome for first and former part of second session. A cross-over selection pattern in favor of long-term outcome has been observed in the latter part of the second session. It seems that the emergence of rule consciousness in the selection process facilitates the subject moving from a myopic situation to a more rational choice state. However, it is worth noting that the subjects were still dominated by the effect of gain-loss frequency even in the first half of the second session. We thus have reasons to suspect that a possible knowledge of gamble structure might have been present in the administration of Iowa Gambling Task (Bechara, Damasio, Damasio, & Anderson, 1994). Similar finding is also reported by Maia & McClelland (2004). If this is really the case, a partial resolution of the above-mentioned discrepancy can hopefully be suggested.

Title: Discounting of Delayed Monetary Reward in Major Depressive Disorder (MDD)

Authors: Bernhard Connemann, Christoph Bux, Nenad Vasic, Christian Wolf, Georg Gron, Manfred Spitzer

Institution: Department of Psychiatry III, University of Ulm

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Web address URL for a paper (if available):

Abstract text (fill no more than this page)

A depressed mood as well as anhedonia, decreased goal-oriented activity, and a diminished ability of decision-making are the hallmarks of MDD. There is a reduced perception of reward as a stimulus; patients may appear lethargic and often fail to recognize possible courses of action. Then again, impulsive actions may occur.

The phenomenon of depreciating future reward stimuli also exists in healthy individuals. Generally, the attributed value of a reward or a penalty is a function of time. Phelps and Pollack (1968) described the so-called Beta-Delta -Model that assumes an exponential (Delta) devaluation as well as a uniform downweighting of all later points in time. Green et al. (2004) showed a comparable `Discounting' in rats and doves and Stevens et al.(2005) found similar reward-related behavior in two species of monkies. In humans, a marked depreciation of future rewards was demonstrated in alcohol addiction, in opiate addiction and in pathological gaming. In an fMRT examination McClure et al. (2004) showed frontomedial and cingular cortical areas to be responsible for impulsive choices and lateral prefrontal regions to be involved in more patient, future-oriented decisions.

A disruption in these systems may be the origin of the disturbed evaluative behaviour in MDD, in accordance with 18F-FDG-PET findings of a hypometabolism in the dorsolateral prefrontal cortex. As a consequence, frontomedial activations in the course of choice paradigms should be less pronounced in depressed patients than in healthy individuals; moreover, the decisions for an immediate option should differ in MDD less than in normal individuals from that of a later option concerning the activity of these structures.
This leads us to scheduling an investigation in which patients with MDD, moderate or severe, and healthy test persons are to repeatedly choose between a later payment of a bigger or an immediate payment of a smaller ammount within an event-related fMRT-paradigm. The compared events are the decision for the earlier or later option; the analysis rests upon statistical parametric mapping (SPM5) and the general linear model, target parameter being the activation of the frontal cortex and, in particular, the interaction between the effects of factors `option' (earlier versus later) and `group' (MDD versus healthy). Using a related paradigm, electrophysiological correlates of impulsive decision are studied.
We hope to demonstrate a reduced involvement of frontomedial structures in impulsive decision-making in MDD. Any reproducible difference might lead to establishing a physiological parameter for characterising MDD, which currently is exclusively defined on the behavioral level. This would be an important step in the direction of an etiopathogenetic understanding of MDD.

Title: Incentive value or incentive salience? Comparing two accounts of nucleus accumbens function

Authors: Jeffrey C. Cooper, Jamil Bhanji, & Brian Knutson

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Abstract text (fill no more than this page)

Neurons in the nucleus accumbens (NAcc) respond during anticipation of a variety of incentives (Schultz, 1998; Knutson et al., 2001), but their role in incentive processing remains ambiguous. For instance, it is unclear whether NAcc activates preferentially during reward anticipation (Schultz, 2004; Knutson et al., 2005) or, instead, responds to more generic features of rewarding situations, like salience, arousal, or uncertainty (Berridge & Robinson, 1998). We aimed to disentangle conflicting predictions made by these theories by systematically varying valence and arousal in an incentive-processing task and comparing anticipatory brain activation between conditions. We used both monetary rewards and punishments to manipulate valence, and varied the certainty of the outcome to manipulate arousal/salience; we used within-trial affect probes to verify participants' subjective reactions to differing incentive and certainty levels. We hypothesized that NAcc activity would correspond to situations involving both positive valence (reward > punishment) and high arousal (uncertain > certain). In line with these hypotheses, we found that bilateral NAcc activity was increased for reward trials relative to loss trials when outcomes were certain, but that NAcc was activated by both gain and loss trials when outcomes were uncertain. These neural results suggest that both arousal and reward activate the NAcc. NAcc activity may represent a nonlinear combination of two separable computations in reward processing: arousal and incentive value.

Title: Reinforcement learning: Studying the development of preferences with a known optimal policy for learning

Authors: E. J. DeWitt, M. Dean, P. W. Glimcher

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Abstract text (fill no more than this page)

Classic studies of reinforcement learning show that animals from pigeons to humans match their allocation of choices to the ratio of rewards received in concurrent variable interval (CVI) schedules, a behavior characterized by Herrnstein as the Matching Law. While behavior of this type may be efficient under some conditions, a formal definition of optimal decision making under dynamic VI schedules of the type usually studied by neurobiologists and psychologists has not been possible.

We therefore developed a close analogue of the original CVI task, formally an n-armed bandit. Each bandit arm yields a payoff drawn from an independent gaussian process with a drifting mean, where the drift is drawn from a second gaussian distribution after each round. Importantly, bandit arms drift only after an arm is chosen. This allows the use a Gittin's index solution to specify the best action on a choice-by-choice basis. The optimal policy relies on a continual estimate of the underlying expected value of each arm. This estimate is calculated using a Kalman filter. The Kalman update function has the form $z_{t+1} = z_t + K(x_t - z_t)$, where z is the estimate of the underlying expected value, x is the observed outcome and K is a learning rate determined by the Kalman filter. We employed a bandit of this type because this update function has exactly the same form as standard reinforcement learning models, $v_{t+1} = v_t + \alpha(r_t - v_t)$, where a value estimate v is updated based on a received reward, r. This allows us to state that reinforcement learning is an optimal policy in our task and further to specify the optimal learning rate for any given set of parameters.

We ran 28 subjects in this task using parameters that specified different optimal learning rates for the ideal decision maker. Subjects were run in fully independent blocks of 50-80 rounds with a signal between blocks that indicated a new set of initial conditions. Each subject completed 10-16 blocks in a session. Subjects were provided full information about the task and were paid a percentage of their actual choices on completion, earning approximately $25. We systematically varied the task parameters our subjects encountered so as to vary the learning rates they should produce. We then fit reinforcement learning models to the observed choices and compared measured and predicted learning rates. Our data show that humans consistently use learning rates that are faster than optimal for the task parameters, but respond appropriately to changes in the environment.

Dopamine carries a reward prediction error signal in non-human primates (Schultz, 1998; Bayer, 2005). Our approach should allow us to test the hypothesis that dopamine underlies reinforcement learning in humans. We are currently developing novel techniques necessary to accurately measure midbrain dopamine activity during our task—techniques that are at the edge of current fMRI practice.

Title: A mechanism for human choice

Authors: John Dickhaut, Ovidiu Lungu, Baohua Xin and Aldo Rustichini

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Abstract text (fill no more than this page)

We use a classical economic choice task in both risky and ambiguous settings. We study when a sequence of certainty stimuli is compared to a baseline stimulus (either risky or ambiguous). We show activation reflects a specific decision variable (whether a stimulus is more preferred than a baseline). Preferences for certainty stimuli is contingent on whether activation for specific stimuli have crossed an indifference barrier. Background for this result is Dehaine Et. al.'s model of number comparison. Both risky and ambiguous stimuli settings share the common feature of reflecting a comparison process that is based on activation sums having crossed a critical barrier; however, the magnitude of the barrier is not independent of the stimuli under consideration. In particular it is hypothesized and confirmed that for ambiguous stimuli the size of the barrier is corrected for the quality of information that is being examined, while the human brain makes no such correction for risky stimuli. This differential adjustment of barriers produces the important result that activation (in parietal cortex, BA 6 and precuneus) and reaction time are less for ambiguous as compared to risky stimuli. This key result for reaction time has been shown in several other studies but is explained here. We test our hypothesis in two sets of experiments where subjects had to choose among different lotteries.
•The activation in parietal, BA 6 and precuneus is not the only activity occurring during choice. Activation in orbital frontal cortex reflects two subtle properties. First the pattern of activation in orbital frontal cortex is negatively correlated with activation in parietal, BA 6 and precuneus while choice is being made. Secondly in after choice there is significant activation in orbital frontal cortex. The magnitude of this activation differs as a function of whether the subject chose a certain or uncertain (risky or ambiguous) amount reflecting that even in after-choice there is neuronal evaluation.

Title: Influence of attention on brain responses to appetitive and aversive stimuli.

Authors: Brent A Field, Cara L Buck, Samuel M McClure, Daniel Kahneman, Jonathan D Cohen

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Abstract text (fill no more than this page)

Cognition is composed of both automatic (e.g., affect) and controlled (e.g., attention) processes that may now be studied non-invasively in people using fMRI. In this project, we test whether the strength of an hedonic experience (as reflected in brain activity) is diminished if one is distracted by an attentionally demanding task. Participants in the study were given small squirts of appetitive (fruit juice) or aversive (quinine hydrochloride solution) liquid orally. Simultaneously, the subjects were alternately engaged in a zero-back or three-back working memory task, which respectively required small or large attentional load. We found that there is a significant interaction between the solution and the difficulty of the task in several brain regions previously associated with affective processing. These areas include the ventral striatum, amygdala, and ventromedial prefrontal cortex. These findings reflect the fact that responses in these brain areas are diminished, and become more similar for juice and quinine, when subjects perform the 3-back task compared with the 0-back task. These data suggest that attentional allocation may directly influence hedonic experience at the level of brain areas implicated in basic reward processes.□

Title: Law and Human Flourishing: Affective Neuroscience, Happiness, and Paternalism

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Web address URL for a paper (if available):

Abstract text (fill no more than this page)

This paper analyzes legal implications of affective neuroscience It examines in which decision-making environments, are there categories of paternalism that are justifiable by considerations of an individual's happiness or subjective well-being? Recent affective neuroscientific data provides evidence of a disjunction between two brain systems: wanting and liking. In *Wanting, Liking, and Learning: Speculations on Neuroscience and Paternalism*, 73 U. Chi. L. Rev. 87 (2006), Professor Colin S. Camerer has recently this gap between wanting and liking supplies a scientific language for normative and positive theories of paternalism. This paper examines policy consequences of empirical findings in affective neuroscience and positive psychology for a recent debate among behavioral economists and legal scholars about paternalism. This paper advocates that situations of judgment and decision-making (JDM) which present challenging learning environments (CLE), including but not limited to addiction resulting from cue-triggered decision processes; or decisions with irreversible consequences (DWIC) or very costly to reverse consequences, justify some type of paternalism. An example of paternalism towards CLE or DWIC is that of parents engaging in paternalism, or parentalism, if they believe their children face CLE or DWIC, such as risk of permanent bodily injury, irreparable harm, or death. Mere repetition of CLE or DWIC does not ensure any mastery of relevant knowledge or skills. There are well-known cognitive limitations to learning, such as overcorrection; and also affective or emotional influences that can help or hinder learning.

Title: Decision or response preparation? Separating decision making from motor actions

Authors: Kaisa Hytönen[1,2], Oliver Langner[2,3], Vasily Klucharev[1,2], Ale Smidts[1], Ivan Toni[2,4], Jens Schwarzbach[5]

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Abstract text (fill no more than this page)

Decision making is composed of multiple subprocesses that are not easily separable from each other. Sensory input is transformed into a neural representation after which the representation of stimuli is transformed into probabilities of choice, *e.g.* by categorizing the stimuli with respect to decision criteria. These probabilities are transformed into a decision that is translated into a plan for motor actions. While this description implies an order of processing, these processes can be continuous and do not necessarily have to be discrete and sequential. This means that response preparation can already emerge while the decision is being made. However, development of decision-making models requires a clear separation between decision making and motor actions.

Previously, lateral intraparietal area (LIP), superior colliculus (SC), frontal eye fields (FEF), and dorsolateral prefrontal cortex (DLPFC) have been found to reflect decision related activity in single cell recordings with monkeys (*e.g.* Shadlen, 1996; Shadlen, 2001; Horwitz, 2004; Gold, 2000; Kim, 1999). These studies used a perceptual 2-choice decision task where the animals were able to prepare for a response while forming a decision. But because LIP, SC, and FEF are involved in the production of eye movements, their activity could be interpreted as response related activity when monkeys have to signal their decision by saccades. Interestingly, in a task where advance response preparation was impossible, no decision-related LIP activation was found (Gold, 2003).

Recently Heekeren et al. (2004) reported a perceptual decision-making area in the left DLPFC in the human brain. But similar to most of the monkey studies, the design was not sensitive to separate decision and motor preparation. Further, no motor related activations were reported.

The goal of the present study is to reveal decision areas in the human brain that are independent of response preparation. Our strategy is to disentangle decision making and response preparation in time. Ten participants viewed for 1 s randomly presented clear and noisy images of faces and houses, and decided whether they saw a face or a house. They reported the decision after a jittered delay period when a response cue appeared. To prevent motor preparation during the decision-making phase, two response modalities and two response mappings were assigned randomly for each trial, and indicated by the response cue. We recorded event-related fMRI while participants were performing the task.

To identify brain regions related to decision making, we adopted a model for perceptual decision making that was introduced by Shadlen et al. (1996). In the model, activity in face- and house-responsive areas (fusiform face area (FFA) and parahippocampal place area (PPA), respectively) are taken as the input signals to a decision process. The model assumes that (1) decision activity correlates with $|FFA(t) - PPA(t)|$, and (2) decision activity is higher for easy than for difficult decisions.

In the present paradigm, action preparation is prohibited during decision making by introducing a randomly assigned response mapping for each trial. Our results are discussed as a general mechanism for human decision making, and we aim to demonstrate that we are able to separate motor preparation from decision making.

Title: Melioration through Adaptive Threshold Adjustement in a Drift Diffusion Model of Decision Making

Authors: Patrick Simen, Philip Holmes and Jonathan D. Cohen

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Abstract text (fill no more than this page)

Psychological research into choice and decision making behavior has traditionally been carried out in largely non-overlapping domains. Here we examine two of these domains and show that a single model can unify successful models in each domain. In the reaction time domain, originating in the work of Donders, the focus is on the latency and accuracy of individual responses to input stimuli. In the domain of operant psychology, originating with the work of Skinner, the focus is on rates of responding; here the parameters of a reinforcement schedule are the primary independent variables. We have previously examined an adaptive version of the classic drift-diffusion model of decision making, implemented as a simple neural network model, that accurately captures reaction time and accuracy in two alternative forced choice decision tasks. This version of the model continuously modulates its response threshold so as to maximize its expected rate of reward. By maintaining a local estimate of reward rate and reducing response thresholds in proportion to increases in this estimate, it can account for speed-accuracy tradeoffs in two alternative forced choice tasks. Here we show that when the same model is applied to tasks in which a reinforcement schedule is the primary manipulation, the adaptive model behaves on average like Herrnstein's melioration mechanism. As a result, the predicted allocation of choice proportions is approximately the same as that predicted by the matching law of operant psychology. The threshold modulation mechanism we propose may therefore serve as a link between successful, but disconnected, psychological theories. We show that it may also explain recent findings in primate electrophysiology.□

Title: Working more for less: a review of seemingly paradoxical work schedules in humans and animals

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Abstract text (fill no more than this page)

We review some of the literature on seemingly paradoxical situations in which humans or animals work more avidly for smaller rewards than for larger ones. In particular, we examine the backward-bending labor curve in economics, and the inverted-U shaped dose-response curve in animal studies of drug-seeking behavior. In both cases, response rates increase when rewards per unit of work are increased from low to moderate levels, but decrease again as rewards reach very high levels. Theoretical explanations for both phenomena are well-recognized in their respective fields, and bear some striking similarities. However, a lack of crucial pieces of data make it difficult to compare and contrast the behavioral findings in the economics and neuroscience literatures. Although we do not present new data, we identify a number of potential avenues for further inquiry, drawing on studies from labor economics and behavioral neuroscience. In the animal literature, some of these areas include the relative paucity of data regarding non-drug rewards, as well as a lack of comparisons between short-term and long-term changes in reward schedule (which might be expected to show opposing effects), and between open and closed economies. In the economics literature, it appears that more data may be needed regarding individuals with very high incomes, where the backward bending labor curve might be hypothesized to be especially prominent. Although these two separate literatures have very different areas of focus, they may both provide insight into related behaviors in humans and animals.

Title: Time consistency in temporal discounting: Behavioral evidence and neural mechanisms

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Abstract text (fill no more than this page)

Previous experiments have demonstrated that the subjective value of delayed rewards declines as a hyperbolic function of delay. This suggests that people will exhibit *preference reversals* of the following type: right now you prefer receiving $25 in 13 months to $20 in 12 months, but if asked again one year from now, you would switch your choice to $20 immediately instead of $25 in 1 month. Alternatively, making the same choice one year from now would be an example of *time consistency.*

However, previous studies have usually measured the subjective value of delayed rewards relative to an immediate reward, a process that confounds the absolute delay to a reward with the relative difference in the delay between the two rewards. This distinction is critical because only a hyperbolic decline with absolute delay leads to preference reversals; a hyperbolic decline with relative delay leads to time consistent choices. In the present experiment, we tested whether subjects' behavior and corresponding neural activity was best described as a function of the absolute or relative delay to a reward. Subjects made repeated choices between two monetary rewards while we measured neural activity using functional magnetic resonance imaging. Choices were drawn from two sets: an "immediate" set that involved choices between receiving $20 now and a variable amount ($21-$120) at a variable delay (5-120 days), and a "delayed" set that was constructed from the first by adding a fixed delay of 60 days to both options. Subjects were paid according to their choices on four randomly chosen trials per session, and all payments were made using commercial debit cards that could automatically be incremented at the time of the payment. Perhaps surprisingly, the choices of our subjects were largely time consistent, and the subjective value of delayed rewards was best characterized as a function of the relative delay between two rewards, rather than the absolute delay. Consistent with our previous findings, neural activity in the ventral striatum, medial prefrontal and posterior cingulate cortices varied as a function of the subjective value of the delayed reward in the "immediate" choice set. However, activity in these regions also depended on the absolute delay to reward (i.e., activity differed between the "immediate" choice set and the "delayed" choice set), thus ruling out one potential neural mechanism of time consistency.

Title: Neural Foundations of People-System Relationships

Authors: P. Kenning [1]*, H. Plassmann [1,2]*, C. Backhaus [1]*, D. Ahlert [1] *authors contributed equally to this paper

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Abstract text (fill no more than this page)

Interpersonal relations are crucial in many aspects of economic life (*Bolton and Ockenfels, 2000, Xiao and Houser, 2005, Doebeli et al. 2004, Sanfey et al. 2003, Fehr and Gächter, 2002, de Quervain et al. 2004*). For instance, the decision to trust somebody or to cooperate with him might depend on former experiences, i.e. the relation between those two people (*Kings Casas et al. 2005*). Although there is mounting literature on interpersonal relations, little is known on how relations between people, for instance customers, and abstract systems like "companies", "the police" or "money" arise. From a neuroeconomic perspective, the development of such people-system relationships might correlate with activations in the rewarding system which is crucial for learning and memory, quite similar as this is the case in interpersonal issues (*Redish 2004, Kings Casas et al. 2005*).

Methods:

In order to test this hypothesis, we employed fMRI and used several company brands as symbols for specific system-companies. A total of 300 customers of a specific company were chosen randomly from a club card database. Based on this database, we used purchase frequency to measure the strength of the specific people-system relationship. According to this strength, the sample was divided into two groups: customers with a strong relation to the firm ("S") and customers with a weak one ("W"). During high-field fMRI at 3.0 T, nine males and thirteen females performed brand choice tasks. We employed *Deppe et al. (2005)'s* brand choice task in a modified version, with one of four company brands as the target brand (T). A two-sample t-test was conducted on the group level to compare neural activations patterns of the two groups when T represented choice.

Results and Discussion:

The most pronounced increased activation in the presence of T in the S-group compared to the W-Group was found, as expected, in the striatum ($p<0.001$, corrected, cluster level, $t=5,15$). Furthermore, other areas involved in the TD decision were the activation network linking the ventromedial prefrontal cortex, the ventral striatum and anterior cingulate cortex ($p<0.005$, uncorrected). Thus, our results can be interpreted as first evidence that building people-system relationship might follow the same neural principles than interpersonal relationship building does.

Title: Neural correlates of elation and disappointment in decision-making

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Abstract text (fill no more than this page)

Elation or disappointment is a psychological reaction when the obtained outcome is better or worse than expected. Neural substrates of elation and disappointment are not known and their effects on future decision-making still remains in question. The aim of this study is to understand the role of elation and disappointment in decision-making. 18 subjects perform the "Wheel of Number" Task: This wheel of number has integers from 0 to 30 with an increment of 1. Subjects can choose their desired number with three possible betting strategies (i.e. 0.5X, X, 2X) for 10 rounds. When the wheel stops at the corresponding number, this outcome results in 100% reward and, if not, it results in -100% reward. The same experimental session is repeated, except that the computer offers the randomly-chosen target number for each round. We scan event related BOLD fMRI during decision-making (anticipation) and display of the outcome (elation/disappointment) for the task. Risk-taking strategies of the subjects are assessed using Iowa Gambling Task and their association with the influence of elation and disappointment on future decision-making is examined. Subjects also report the degree of elation/disappointment after each round in the scale of 0-10 by introspection, which is compared with the measured fMRI activation. This study will suggest functional neuroanatomy of elation and disappointment by profiling its activation with correlated rewards and betting patterns and provide us with insight into the role of elation and disappointment in decision-making.

Title: **What is the real function of medial frontal cortex under a complete uncertainty? An fMRI study of the Iowa Gambling Task**

Authors: [1]Ching-Hung Lin, [2]Yao-Chu Chiu, Chou-Ming Cheng, Jen-Chuen Hsieh

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Abstract text (fill no more than this page)

Damasio et al. postulated that the medial frontal cortex (MFC) is crucial for integration of somatic signals and bias monetary decisions under uncertain situations, such as that in the Iowa Gambling Task. Their supporting evidence was obtained for neurological patients who had injuries in brain regions related to emotion representation, especially in the MFC. Rolls et al. proposed that the near-MFC may be the functions of reverse learning which is relevant to "immediate" prospect rather than the integration (accumulation in the long run) of somatic feedback that bias decision making. Roll's argument is mostly based on theoretical prospective and his animal studies, however the method is not fully comparable with the SMH. On the other hand, Ernst et al. in a positron emission tomography (PET) study utilized the revised Iowa Gambling Task and showed that many other brain regions in addition to the not only MFC participate in the Iowa Gambling Task. Fukui et al. fMRI study demonstrated that MFC activity is associated with anticipation of a risky choice rather than a safe choice. The two imaging studies are comparable with SMH in task and method, but they are probe few conditions for the whole picture. To resolve the theoretical problem between the Somatic Marker Hypothesis (SMH) and reverse learning theory on the explanation of MFC function under uncertainty and detail the brain mapping that Ernst and Fukui et al did not demonstrate. This study recruited the event-related fMRI and probed more conditions (anticipation vs. outcome; gain vs. loss; four decks; 11 gain-loss values) in the original IGT to analyze whole brain activity in time and spatial domains. Twenty-four healthy participants (8 males and 16 females; age range, 19-32 years) were enrolled in this fMRI study. Data for 2400 trials (24 subjects × 100 trials) demonstrated that the bilateral insular cortex (IN), lentiform nuclear (LN), right superior temporal gyrus (rSTG), left inferior parietal lobule (lIPL) and cingulate gyrus (CC), and not the MFC, were highly correlated to anticipation of monetary gain and loss. The right inferior parietal lobule (rIPL), superior frontal gyrus (SFG) and left medial frontal gyrus (lMFG) responded to outcomes. In advance of previous finding, separate neural systems were identified between gain and loss conditions during experience and not anticipation. Notably, significant activation of the MFC occurred only in the condition of largest loss of deck B. In conclusion, without knowing the probability and value range in the IGT, the MFC may be not crucial to anticipation during monetary decisions. Conversely, IN and LN, rSGT, lIPL and CC likely have important roles in generating anticipatory feeling and thereby bias the decision-making process. Additionally, the rIPL, rSFG and lMFG may associate value in gain-loss with external conditions. Experimental results indicated that the MFC may monitor conflicts between expectation and outcome. Although, these experimental results were mostly inconsistent with the basic assumption of IGT, they are consistent with many animal and brain-imaging studies that examine reward-punishment mechanism in the brain.

Title: Computation of discounted utilities in the primate prefrontal cortex

Authors: Soyoun Kim, Jaewon Hwang, Daeyeol Lee

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Abstract text (fill no more than this page)

A central goal in the studies of decision making is to discover the rules by which the multiple attributes of the outcomes expected from a given action are combined to compute its subjective value or utility. For example, an action that is followed by a reward after a certain delay might be evaluated by its temporally discounted utility. Accordingly, when choosing between a small but immediate reward and a large but delayed reward, animals and humans might prefer a small but immediate reward. To examine the shape of discount function in non-human primates and to investigate the corresponding neural basis, we trained rhesus monkeys in a novel inter-temporal choice task. Animals began each trial by fixating a small square presented at the center of a computer screen. After a 1-s foreperiod, two peripheral targets were presented along the horizontal meridian. Then, the central square was extinguished following a 1-s delay period, and the animal was required to shift its gaze towards one of the targets. One of the targets was green and delivered a small reward when selected, whereas the other target was red and delivered a large reward. The positions of red and green targets were counter-balanced across trials. In addition, the delay for each target (0, 2, 5, or 8 s) was determined pseudo-randomly, and was indicated to the animal by a clock consisting of a variable number of yellow and cyan dots presented around each target. Once the animal chose its target, dots in the clock for the chosen target were removed one by one at the rate of 1 and 4 s/dot for the yellow and cyan dots, respectively, and the reward was delivered when all the dots were removed. A logistic regression model was applied to the animal's behavioral data using the discounted value of each target as independent variables. We tested exponential and hyperbolic discount functions using the maximum likelihood procedure. The results showed that in the majority of sessions (81%), hyperbolic discount functions provided a better fit to the data. We also recorded single-unit activity from neurons in the dorsolateral prefrontal (DLPFC) cortex, while the animal performed the same task. The activity during the 1-s delay period was analyzed using a regression model including the animal's choice, the position of the large-reward target, and the number of dots for each target. Only the neurons in which this model provided a significant fit to the data (64%) were included in the further analyses. Many of these neurons (63%) modulated their activity according to the position of the large-reward target. This basic model was then compared to a more complex model that also included the delay or discounted value for each target, using a partial F-test. For some neurons, the complex model performed better than the basic model when it included the delay (20%) or discounted value (37%). Therefore, these results suggest that information necessary to compute the discounted utilities as well as discounted utilities themselves might be represented in the prefrontal cortex.

Poster Session II Friday 1:45 – 3:15	
Authors	**Title**
Jeffrey Klein, Rob Deaner and Michael Platt	Parietal neurons encode social and fluid value in orienting decisions
Camelia M. Kuhnen, Brian Knutson	Neural Predictors of Overconfidence in Financial Decision-Making
Venkat Lakshminarayanan, M. Keith Chen, Laurie R. Santos	The Evolution of Decision-Making Under Uncertainty: Framing Effects in Non-Human Primates
Ching-Hung Lin, Yao-Chu Chiu, Yu-Kai Lin , Jen-Chuen Hsieh	Event-related skin conductance in response to immediate monetary gain-loss in the Soochow Gambling Task
Arwen B. Long, Sheila Roberts, Michael L. Platt	Rapid Phenylalanine and Tyrosine Depletion Modulates Macaque Decision-Making
Anup Malani, Daniel Houser	Expectations Mediate Objective Physiological Placebo Effects
Dan Ariely, Jonathan D. Cohen, Keith M. Ericson, David I. Laibson, George Loewenstein, Samuel McClure, Drazen Prelec	Implementing self-control
Benjamin Hayden and Michael Platt	Risk preference in monkeys depends on behavioral context
Robb B. Rutledge, Brian Lau, Stephanie C. Lazzaro, Catherine E. Myers, Mark A. Gluck,Paul W. Glimcher	Parkinson's disease affects reinforcement learning in a dynamic environment
Patrick Simen, Philip Holmes and Jonathan D. Cohen	Melioration through Adaptive Threshold Adjustement in a Drift Diffusion Model of Decision Making
P. Sokol-Hessner, M. Hsu, M. Delgado, C. Camerer, E.A. Phelps	Reappraising Loss Aversion: Manipulating Choices with Emotion Regulation Strategies
Dharol Tankersley, C. Jill Stowe, Scott A. Huettel	Altruism & the Perception of Agency in the Superior Temporal Sulcus
KW Watson and M.L. Platt	Acute tryptophan depletion alters valuation of both social and reproductive images
Martijn Willemson, Ulf Bockenholt and Eric J. Johnson	Three Models of Loss Aversion with Implications for Neuroeconomics
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John Dickhaut, Greg Waymire, Kevin McCabe	Uncovering the Neuronal Bases of Human Behavior in Economic Institutions

Title: Parietal neurons encode social and fluid value in orienting decisions

Authors: Jeffrey Klein, Rob Deaner and Michael Platt

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Web address URL for a paper (if available):

Abstract text (fill no more than this page)

Visual orienting is a well-studied form of decision making in non-human primates. While monkeys perform an occulomotor decision task for juice rewards, the firing of neurons in the parietal cortex correlates with decision variables such as expected value, reward probability, and reward magnitude (Platt and Glimcher 1999). Here we demonstrate this encoding of decision variables extends to more abstract social rewards. While recording from single units in the lateral interparietal area (LIP), our monkeys performed a "pay-per-view" decision task (Deaner et al 2005) that allowed us to estimate the value of viewing socially salient images. The activity of LIP neurons reflects social reward in a manner similar to juice rewards during occulomotor decision making.

Title: Neural Predictors of Overconfidence in Financial Decision-Making

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Abstract text (fill no more than this page)

We sought to find the neural predictors of overconfidence in financial decision-making by combining a dynamic portfolio selection task with fMRI. In the finance literature, overconfidence has been defined as a behavioral bias manifested by either forming overtly optimistic financial estimates (such as when predicting the future return of an asset), or by being overtly certain about the value of these estimates (such as when determining the confidence interval around the estimated future return of the asset). We hypothesized that these two aspects of overconfidence will be predicted by activation in several areas known to be involved in high-level decision making: the medial prefrontal, orbitofrontal and anterior cingulate cortices.

19 Stanford Ph.D. students played the BIAS investment game developed by Kuhnen and Knutson (2005). Subjects had to choose financial assets to hold in their portfolio and their compensation depended on the dividends paid by the selected assets. Subjects were also rewarded if they formed correct estimates of the probability that the chosen stock is the best investment. Our first measure of overconfidence, Overconfidence_In_Estimation, is defined as the differences between this subjective estimate and the true probability that the stock is the right investment. Our second measure of overconfidence, Overconfidence_In_Certainty, is the defined as the subject's assessment of how certain she is of her probability estimate.

We found that activation in the left MPFC, bilateral OFC and left ACING during the period the subject is evaluating the stock are all negative, statistically significant predictors of the subject's overconfidence in estimating the probability that the stock is the right investment. Activation in these areas did not help predict the subjective assessment of certainty in the estimate provided. We also found that females are significantly less certain of their estimate of which stock is best, compared to males. Interestingly, the dividend received most recently by the subject is a positive and significant predictor of both measures of overconfidence.

Title: The Evolution of Decision-Making Under Uncertainty: Framing Effects in Non-Human Primates

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Abstract text (fill no more than this page)

Maximizing access to scarce goods such as mates and food is central to the survival of all organisms. In many real world situations, choices between scarce goods entail some element of risk— deciding, for example, between a low-payoff but less risky mating strategy versus one with a higher but more unlikely payoff. What proximate cognitive strategies do organisms use to decide when to accept risky gambles? A standard assumption is that organisms evaluate uncertain decisions using rational strategies, ones that seek to calculate and then maximize risk-adjusted expected payoffs. In contrast, humans decision-makers seem to evaluate gambles not in terms of their overall expected payoffs, but in terms of how those gambles are framed relative to some reference point, specifically whether the outcome of the gamble is perceived as a relative loss or relative gain. People tend to be more averse to losses than they are disposed to equally sized gains, often leading to different preferences depending on whether risky problems are framed in terms of gains or losses: tax exemptions rather versus tax premiums, mortality rates rather versus survival rates, real wage cuts versus equivalent nominal raises. Here we show that similar framing effects influence the decisions that non-human primates make as well— capuchin monkeys (Cebus apella) treated identical risky gambles differently depending on whether the outcomes of those gambles were framed as gains or losses. The degree to which monkeys accept risk varies with whether they think they are gambling to maximize gains, or gambling to minimize loses. This finding suggests that capuchins, like humans, judge the quality of risky outcomes irrationally based on how a particular problem is framed.

Title: **Event-related skin conductance in response to immediate monetary gain-loss in the Soochow Gambling Task**

Authors: [1]Ching-Hung Lin, [2]Yao-Chu Chiu, Yu-Kai Lin , Jen-Chuen Hsieh

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Bechara et al. designed the Iowa Gambling Task (IGT) to evaluate normal subjects and ventromedial prefrontal patients. Their experimental results indicated that normal subjects can foresee by the favor of intact somatic-markers which can be determined by Skin Conductance Responses (SCRs). The somatic-markers cause decision makers to avoid the decks that result in bad final-outcome and approach the good final-outcome decks in IGT. After approximately 30 trials, normal subjects generated larger anticipatory SCRs before choosing bad final-outcome decks and small SCRs before choosing good final-outcome decks. In IGT, for each unit of 10 cards, the bad final-outcome ($ -250) deck A contains 5 gains and 5 losses; deck B contains 9 gains and 1 loss. Conversely, the good final-outcome ($ 250) deck C contains 6.25 gains, 2.5 standoffs and 1.25 losses, and deck D contains 9 gains and 1 loss. However, Tomb et al. and Suzuki et al. noted that the data for SCRs of normal subjects during IGT have divergent results which were inconsistent with Bechara et al. findings. In addition to these SCRs results, Chiu et al. (2005) designed a revised task namely, Soochow Gambling Task (SGT) which possesses a clearer and symmetrical gain-loss structure than the IGT. In SGT, deck A in the SGT has 4 gains ($ 200) and 1 loss ($ -1050); deck B has 4 gains ($ 100) and 1 loss ($ -650); deck C has 4 losses ($ -200) and 1 gain ($ 1050); and deck D has 4 losses ($ -100) and 1 gain ($ 650). The SGT and IGT have all the same uncertainty and final-outcome structure. Additionally, in the SGT, negative final-outcome decks have high-frequency gain and vice versa. Their result demonstrated that normal subjects were "insensitive" to final-outcome as well as inconsistent with IGT proposition. Nevertheless, little is known about the link between somatic feedbacks and "myopic" behavior in SGT. This study launched the SGT and event-related SCRs to make the experimental content of the SGT more comparable to the serial studies of IGT. Furthermore, to clarify the argument between Tomb, Suzuki and Bechara et al. results. The SGT has a regular monetary value-structure for an easy evaluation of associated SCRs and event-related SCRs offers additional time-resolution detail for depicting signal changes in sympathetic activity. This study recruited 24 college students to perform the SGT. Event-related SCRs recorded sympathetic activation of the anticipatory [(-5(s) - 0(s)] and responsive [(0s - +5 (s)] periods during each trial. Behavioral results replicated in the SGT original finding that normal subjects were "myopic" to the final-outcome. The signal of event-related SCRs demonstrated that the sympathetic activities were less related to "anticipation" of choices, but roughly responded to monetary "outcome" of various gains and losses. This result is consistent with that obtained by Tomb and Suzuki et al. and is counter to those obtained by the Iowa group. The SCRs cannot represent the anticipatory somatic signal and guide decisions. These experimental findings for behavior and SCRs implied that under uncertain situations, subjects are occupied by the immediate gain-loss rather than guided by the final-outcome based on somatic feedback.

Title: Rapid Phenylalanine and Tyrosine Depletion Modulates Macaque Decision-Making

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Abstract text (fill no more than this page)

Dysfunctional decision-making is demonstrated in several neuropsychiatric diseases. In particular, impulsive, or excessively risky, behavior is seen in diseases such as addiction, impulsive personality disorders, and ADHD. Recent work from our lab showed that macaques offered a choice between a certain reward and a variable reward more frequently chose the risky option, and that the neuromodulator serotonin increased preferences for the risky option. Previous work from other labs implicates dopamine, a neuromodulator, in decision-making. Dopaminergic neurons respond to reward as well as to reward variance. Furthermore, dopaminergic pathologies have been implicated in addictive, impulsive, and compulsive behaviors; and drugs that decrease dopamine reuptake, like□ Adderall (amphetamine) and Ritalin (methylphenidate), decrease impulsive behavior. Based on these observations, we predicted that depleting dopamine would systematically modulate risk preferences. To study the effect of dopamine depletion on decision-making under risk, we used Rapid Phenylalanine and Tyrosine Depletion (RPTD), a dietary amino acid manipulation that rapidly depresses serum dopamine and brain dopamine levels, in two male macaques performing a risky choice task. Initial results suggest that RPTD modulates the monkeys' tendency to make risky choices relative to matched control experiments.

Title: Expectations Mediate Objective Physiological Placebo Effects

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A Placebo Effect is a belief-based (positive) change that occurs due to the administration of an inert substance. Placebo effects might be "behavioral", in the sense that new beliefs lead to new decisions which then lead to positive changes. Placebo effects might also include a "physiological" component, which refers broadly to non-behavioral brain-modulated mechanisms by which new beliefs cause positive changes. Nearly all formal economic models of human behavior are consistent with behavioral effects, but strongly inconsistent with their physiological counterpart. The reason is that the latter effects can imply that expectations enter, rather than multiply, state-contingent preferences. It is therefore unfortunate that little evidence exists on physiological placebo effects. We report data from novel clinical experiments with caffeine that seek to provide such evidence. Subjects visit the clinic on multiple occasions. On each visit they ingest either a placebo or caffeine pill. Subjects know only the probability with which the pill includes caffeine. We obtain physiological measurements prior to ingestion, and each 30 minutes thereafter for two hours. Subjects remain seated during the two-hour session, with only airline magazines available to read to pass the time. Our design provides particularly clean inference because it (i) eliminates the possibility of behavioral confounds; (ii) provides for measurements at the individual level; (iii) manipulates beliefs without deception; and (iv) uses salient rewards. We find compelling evidence for the existence of physiological placebo effects, and that these effects are mediated by expectations. Our results are consistent with the possibility that the PFC provides external, top-down control that modulates physiological outcomes. Our evidence makes a strong case for the importance of research geared toward developing appropriate and tractable frameworks that accommodate non-linear relationships between expectations and preferences.

Title: Implementing self-control

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Economists and decision theorists have classically viewed intertemporal choice as a matter of weighing costs and benefits occurring at different points in time, with later costs and benefits discounted according to an exponential or hyperbolic function. However, recent perspectives have shown that a variety of anomalous patterns of behavior can be accounted for by modeling intertemporal choice as a competition between two separable neural systems, one which is more far-sighted and one which is more present-oriented (Thaler & Shefrin, 1981; Loewenstein, 1996). Such a dual system account of intertemporal choice was supported by brain imaging experiments which found that both affective and deliberative systems were invoked by choices between immediate and delayed rewards, whereas only deliberative systems were evoked in choices between delayed and even more delayed rewards (McClure et al., 2004).

However, very little work has aimed to understand how the deliberative system implements a far-sighted choice - i.e., the neural mechanisms underlying self-control. Here, we report on an experiment in which subjects choose between a more abstract reward -- obtaining money at a 1 month delay - and a more emotionally compelling reward -- viewing an alluring photograph - and had to respond continuously to avoid seeing the photograph and receive payment. This scenario is advantageous experimentally since the decision-making process is prolonged, allowing us to obtain several measurements of brain activity as self-control is imposed.

Title: Risk preference in monkeys depends on behavioral context

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Abstract text (fill no more than this page)

It is well-known that both humans and animals systematically deviate from normative ideals when choices involve risk. Although the optimal payoff for any particular gamble can be determined by multiplying the payoffs for each option by their probabilities and choosing the option with the highest expected value, subjects consistently show preference for either risky options (risk-seeking) or non-risky options (risk-aversion). Prior research has implicated internal variables such as physiological state, wealth perception, and even personality in risk preferences. Here we demonstrate that contextual variables external to the subject also influence risk preference. Specifically, we demonstrate that decreasing the time interval between independent gambles (the ITI) increases preference for risk in monkeys performing a decision-making task. These results support the idea, initially proposed by Rachlin, that subjects evaluate the expected payoff of an option by considering the outcome of the next several gambles, rather than considering only the outcomes for the present decision. These results demonstrate that risk preferences are highly context-dependent, and obey systematic principles. Context-dependent risk preference predicts systematic effects of task context on neural circuits contributing to decision-making.

Title: Parkinson's disease affects reinforcement learning in a dynamic environment

Authors: Robb B. Rutledge, Brian Lau, Stephanie C. Lazzaro, Catherine E. Myers, Mark A. Gluck, Paul W. Glimcher

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A recent study has examined human choice behavior in the concurrent variable interval (CVI) environment widely used by psychologists to study animal reinforcement learning (Rustichini et al., 2005). In that experiment, subjects repeatedly chose between two options with different probabilities of reward. In accord with standard CVI processes, the probability that an unsampled option yields a reward was incremented after each trial. Under these conditions subjects distribute their choices so that the ratio of choices equals the ratio of rewards. Similar studies in monkeys have demonstrated that reinforcement learning models (cf. Rescorla & Wagner, 1972; Camerer & Ho, 1999) accurately predict monkey choice behavior under these conditions, even when reward rates dynamically change from block to block in an unsignaled manner (Sugrue et al., 2004; Lau & Glimcher, 2005).

We have developed a discrete CVI-based task to study human choice behavior in a dynamic environment similar to that used in monkey experiments. On each trial, subjects choose one of two options (displayed as animated crab traps). Rewards (crabs worth $0.10) were scheduled for the two targets with different independent Poisson rates. Scheduled rewards remained available until the associated target was chosen, as in the original CVI schedule (Herrnstein, 1961). After a 5-minute training period, subjects completed 800 trials as we varied the CVI reinforcement probabilities across 10 blocks of 70-90 trials. Under these conditions, we found that reinforcement learning models accurately predicted both steady-state and trial-by-trial choice dynamics in humans as they do for monkeys.

The midbrain dopamine system is thought to encode the reward prediction error signal required by reinforcement learning models (Schultz et al., 1997; Bayer & Glimcher, 2005). Loss of neurons within the substantia nigra in Parkinson's disease (PD) might therefore affect reinforcement learning and hence predictably influence choice in this environment. To address this hypothesis, PD patients completed two sessions of our task, one on and one off dopaminergic medication. Age-matched controls completed one session. We found that reinforcement learning is similar in PD patients on medication and age-matched controls, but altered in the same PD patients off medication. These data support a role for dopamine in normal human reinforcement learning and demonstrate that damage to the dopamine system affects choice in a manner predicted by these algorithmic models.

Title: Reappraising Loss Aversion: Manipulating Choices with Emotion Regulation Strategies

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Research in behavioral economics has suggested that people weight losses more heavily than gains. Under prospect theory, this is represented as the increased magnitude of the loss aversion coefficient lambda. It has been argued that emotions may play a significant role in this effect (Loewenstein, 2001; Camerer, 2005), and given that psychological studies have shown that cognitive strategies can alter emotional responses (Ochsner et al, 2002), perhaps similar strategies can be used to alter loss averse behavior. In the current study, we explored the effect of different cognitive strategies on estimates of loss aversion in a monetary decision task.

We developed a set of 140 monetary choices using a parameter recovery exercise to enhance parameter fitting to behavioral data. Participants made choices between risky binary gambles and guaranteed outcomes, after being endowed with $30 prior to the beginning of the study. Payment included a subject fee and the actual value of a subset of trials (with no maximum and a minimum of -$30). We were able to reliably recover accurate value parameters, and demonstrate loss aversion in our participant pool.

We investigated the effect of two different cognitive regulation strategies upon decisions. The first was based upon economic theories of myopic decision-making and framing (Thaler et al, 1997), while the second derived from previous research on emotion regulation (Delgado et al, 2004). For all participants, one full set of choices was made while evaluating each choice in isolation from any context, and refraining from controlling affective responses ("attending"). A identical second set of choices was made with one of two possible instructions. Half the participants reappraised the decisions by considering them in their temporal context, adopting a "portfolio" approach. The other half of participants cognitively regulated their affective responses to the monetary values in each decision, while still considering it in isolation. Relative to attending, the "portfolio" approach reliably decreased estimates of lambda without affecting other value function parameters. The emotion regulation strategy also changed lambda, but the pattern was less predictable, potentially mediated by an overall dampening of positive and negative affective responses to the monetary decisions.

In the present study, we were able to develop a robust procedure for reliable estimation of value function parameters, demonstrate loss aversion in monetary choices, and decrease loss aversion within subjects using cognitive regulation strategies. In the future, we plan to investigate physiological (galvanic skin response) and neural (fMRI) correlates of regulation strategies during economic decision-making..

Title: Altruism & the Perception of Agency in the Superior Temporal Sulcus

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Abstract text (fill no more than this page)

The propensity for altruistic behavior is an important aspect of human social interactions, and the degree to which individuals have altruistic tendencies influences their preferences and the way they make decisions in economic and social contexts. The neural mechanisms by which altruism influences these behaviors, however, remain mysterious. To investigate the neural bases of altruism, we measured brain activity while subjects performed a modified version of the monetary incentive delay (MID) reaction-time task to win money for themselves or for a charity. We arranged the task in a 2 x 2 factorial design with manipulations of Player (Subject vs. Computer) and Recipient (Subject vs. Charity). Trials began with an instruction screen in which subjects were told who would be the player and the potential recipient for the trial, followed by a fixation screen, and then a target cue. If the subject or computer responded quickly enough, money was earned for the recipient on that trial. After the scanning session, subjects completed a self-report altruism questionnaire.

A small set of brain regions exhibited greater activation when subjects watched the computer play the game than when the subjects played the game themselves. These included the posterior cingulate cortex, bilateral posterior superior temporal sulcus (pSTS), bilateral parahippocampal cortex, the right temporal pole, and the right dorsolateral prefrontal cortex. Greater activation was seen in a much more distributed set of regions in fronto-parietal and fronto-striatal areas in the opposite contrast, when subjects played the game vs. when subjects watched the computer play the game.

We next evaluated whether the activation in regions with greater responses to a computer actor was modulated by subjects' self-assessments of altruism. Altruism scores predicted BOLD activity in the posterior cingulate cortex and pSTS. Specifically, higher altruism scores correlated with increased activity in these regions during trials on which the computer performed the task, and decreased activity when subjects performed the task. Hierarchical regression analyses revealed that the right pSTS was the only region that independently predicted intersubject differences in altruism scores. We interpreted these data as showing that altruistic subjects are more willing to attribute agency to a computer, and that the right pSTS is selectively involved in attributions of agency.

Title: Acute tryptophan depletion alters valuation of both social and reproductive images.

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Abstract text (fill no more than this page)

Behavioral decisions reflect the expected value of available options. Furthermore, recent studies suggest that the manipulation of neuromodulatory systems can alter both mood and social behavior. These observations raise the question of whether these systems alter the subjective value of specific types of reinforcers. To address this issue, we used a "pay-per-view" choice task to measure the value of orienting towards sets of images. On each trial a male rhesus monkey fixated a central yellow square. After a delay, two targets (T1, T2) were illuminated and, following the offset of the central stimulus, the monkey was free to shift gaze to either target. Juice delivery followed gaze shifts to T1 while both juice and display of an image followed gaze shifts to T2. The amount of juice delivered for shifting gaze to T1 and T2 varied across blocks of 30 trials, while a different pool of images was displayed at T2 every 150 trials. Image pools comprised 20 frontal images of each of 12 familiar individuals or 20 posterior images of 4 familiar females. Varying the outcomes for orienting to T1 and T2 permitted us to estimate the value of orienting to images in units of fluid. Under normal circumstances, male monkeys will pay a fluid premium to view images of female perinea and the faces of dominant individuals, but are indifferent or averse to images of subordinates. We found that acute tryptophan depletion, which decreases the amount of serotonin in the central nervous system, modulated the value assigned to both social and reproductive images. These findings suggest that serotonin is an important factor in social motivation and decision-making.

Title: Three Models of Loss Aversion with Implications for Neuroeconomics

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Abstract text (fill no more than this page)

Surprisingly little imaging data has provided evidence of one of the most robust behavioral phenomena, Loss Aversion. We examine the processes underlying loss aversion and reference dependence in choice by considering three possible explanations for the effect: (1) The explicit coding of options as gains or losses as characterized by Prospect Theory, (2) The accumulation of evidence by sampling of the options, as characterized by Sequential Sampling Models such as Decision Field Theory and the Leaky Competing Accumulator model, and (3) an increase in biased perceptions of the attributes of an option, Choice by Preference Construction, as described by Decision by Constraint Satisfaction and Pre-Decisional Distortion. For each process we develop a set of predictions which we then test using the information acquisitions made by decision-makers. We also develop methods for the representation and analysis of this data, and assess the ability of each process explanation to account for the data. Our results suggest that loss aversion has an indirect result most consistent with Choice by Preference Construction. These three models each have a different potential for neural activity, and the emergence of Choice by Preference Construction provides new insights which may inform future imaging efforts

Title: Is Isolation Effect in Prospect Theory A Rule or An Exception?

Authors: 1Yao-Chu Chiu, 2Shuyeu Lin, Shaoling Wang, Ching-Hung Lin & 3Jong-Tsun Huang

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Abstract text (fill no more than this page)

At the heart of Prospect Theory (Kahneman and Tversky, 1979) is the notion that the carriers of value are changes of wealth , rather than final states. Thus it is the classification of current and isolated decision outcomes instead of final asset that determines the risk attitudes. This is known as the Isolation Effect. Based on this key assumption, Prospect Theory further suggests two important properties of the value function: "(1) decision outcomes can be classified as either "gains" or "losses"; (2) decision makers tend to show the risk aversive attitude in gain situation and a risk seeking attitude in loss situation." This study provides evidence that argue against the Isolation Effect and consequently, the two suggested properties in Prospect Theory's value function. Various tasks in Prospect Theory, such as the Asian Disease problem, were used in our experiments. Our task design tried to make asset information, as in real life, more comparable and thus more meaningful to the subjects. Instead of not providing any information concerning population size (or, asset) of the city, four levels of population information were presented in the task . For example, in the revised Asian Disease problem, subjects (n=48) were asked to acknowledge that the four cities (A, B, C and D) each has 600, 6000, 600 thousand, or 6 million residents respectively. They were then requested to answer the original Asian Disease problem for each city. The results showed that subjects tend to be risk-seeking when the asset level is high (such as in cities B, C and D) and risk-aversive at low asset level (such as in city A). The result is obviously in contradiction with the prediction of Prospect Theory, in which no differences should be adhered to the different levels of asset. To further validate our results, in addition to the typical group test and hypothetical questions, our experiments also include individual test and provide real money as incentive. In conclusion, isolation effect is not confirmed across various conditions in our study. We thus argue that taking asset into account is a rule rather than an exception in decision making. Isolation effect as suggested by Prospect Theory may be an exception rather than a rule in real-life decision situation.

Title: Uncovering the Neuronal Bases of Human Behavior in Economic Institutions

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Abstract text (fill no more than this page)

•A core economic undertaking is to understand the way exchange is secured through social institutions. Such institutions can be economy wide (including language, the law, politics, etc.) and local (such as rules of corporate governance and control.) Institutions often play the important roles of promoting bilateral trust and fostering reputation building. Drawing on observations from anthropology (Schmandt-Besserat, D., 1995, Vanstiphout, H., 1995) we focus on the recordkeeping; in particular we ask if a technology that creates transactional memory external to the brain promotes the emergence of large-scale cooperation. Note such phenomena are part of Sumerian and Mesopotamian history. There are two studies. First we explore behavioral findings that show recordkeeping ameliorates challenges to memory in multi-person exchange (Basu,Dickhaut,Hecht,Tafkov,Towry and Waymire,2006.) We vary the number of partners in a multiple-period trust game. In the simple setting each player is paired with one other party; in the complex setting, with five other parties. In a computerized setup potential recordkeeping may emerge because individuals are supplied with a blank text box on which they can, if they wish, write anything. In this setting recordkeeping emerges endogenously, and there is more recordkeeping in complex than simple settings. Recordkeeping increases gains to trade in a complex setting. Most importantly recordkeeping substantially changes how societies produce social norms.

•The second study explores neuronal processes that underly institutional development. First we assess brain mechanisms that are challenged with increased economic complexity. If we assume a theory of mind governs exchange (McCabe Et al. (2001), and Rilling, Sanfey Et al. (2004)), then there is postulated to be heightened attention for detecting untrustworthy behavior (see Cosmides (1989)) in the complex setting. McCabe, Rigdon, and Smith (2003) use both voluntary and involuntary trust games to assess a potential role for a theory of mind. When the trustee in the game can detect that the trustor has been trusting (the voluntary trust game) there is much more trustworthiness on the part of the trustee, supporting a theory of mind interpretation. In the trustee we assess differential brain activation of areas generally construed to support a theory of mind including the paracingulate cortex, BA10, and superior temporal sulcus in simple and complex settings. The latter contrasts are combined with contrasts of both dorsolateral prefrontal cortex as well as hippocampus to assess demands on memory under complexity. In the recordkeeping setting the previous trusting behavior of senders is tabulated for the trustee. We then assess different brain mechanisms associated with the recordkeeping and non-recordkeeping manipulations. The net result of the two studies will be both a demonstration of the endogeneous development of an economic institution, namely record keeping, along with the neural determinants of such an institution.

Friday, September 8, 2006

Session II
Risk

3:30 – 4:00 pm	Elke Weber	Neural substrates of risky decision making	Columbia University
4:05 – 4:35 pm	Kerstin Preuschoff	Human insula activation in a monetary gambling task reflects uncertainty prediction errors as well as uncertainty levels	California Institute of Technology

Session III
Prospect Theory

4:40-5:10 pm	Ming Hsu	Probability weighting function in the brain	California Institute of Technology
5:15 – 5:45 pm	Greg Berns	A neurobiological derivation of prospect theory and experimental evidence over losses	Emory University

Title: Neural Substrates of Risky Decision Making

Authors: Hannah M. Bayer (1), Mauricio Delgado (2), Jack Grinband (3), Joy Hirsch (3), Elke U. Weber (1)

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Abstract text (fill no more than this page)

Using both single unit physiology in animals and functional magnetic resonance imaging in humans, researchers have begun to examine how the brain encodes information about some of the variables used by models of risky decision making. Building on these studies, we used fMRI to measure human brain activation while subjects made judgments about two outcome options which were identical in expected value but differed in variance (the index of riskiness used widely in economics, e.g. risky options pricing models like CAPM). Subjects also provided reports about their affective reactions to these options. This allowed us to ask whether there were correlations between brain activation and both objective and subjective characteristics of the risky option set. Our findings confirm the importance of several key structures, including the insula and the anterior cingulate, in deciding between options when all outcomes are risky. It was also observed that in the insula, activity levels were correlated with individual differences in reported concern ratings. In addition, we were able to identify two areas in which activation was unique to the processes involved in choices based on the riskiness of the options themselves. These areas were located at opposite ends of the cingulate cortex, one anterior, the other posterior. Taken together, these results suggest that in addition to a network of brain structures underlying the processes required for deciding among risky options, additional neural resources may also be recruited in order to evaluate the property of riskiness itself.

Title: **Human Insula Activation In A Monetary Gambling Task Reflects Uncertainty Prediction Errors As Well As Uncertainty Level**

Authors: Kerstin Preuschoff, Peter Bossaerts and Steve Quartz

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Web address URL for a paper (if available):

Abstract text (fill no more than this page)

In the Somatic Marker Hypothesis (SMH), the insula plays a prominent role in relaying somatosensory input that is relevant for sound decision making. In the context of monetary gambles, however, the uncertainty signal previously identified in imaging studies appears to arrive too late to possibly have an effect on decision making. We find a second, timely, uncertainty signal, in an area of insula slightly more posterior and ventral. This newly discovered signal may be interpreted as an uncertainty prediction error (it correlates negatively with the difference between uncertainty in a trial and general uncertainty across all trials). Accordingly, we find a corresponding uncertainty prediction error at the time of reward (the difference between the size of the surprise and prior uncertainty). Our results obtain in a situation of pure risk; there is neither ambiguity nor learning. Together with prior accounts in the literature, this suggests that insula is involved in evaluation of uncertainty both when probabilities are known and when they are not. Our experimental paradigm allows us to ascertain that insula activitation is not merely motivational – induced by the act of choosing – but emerges because of perception of uncertainty. The uncertainty signal in insula correlates perfectly with reward variance, which is the main parameter of uncertainty in the theory of financial decision making. This finding may explain why insula activation predicts risk-avoiding choices in humans. We do not find any evidence of an expected reward signal. Hence, insula specializes in evaluation of uncertainty

Title: Probability Weighting Function in the Brain

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Abstract text (fill no more than this page)

That people weight probabilities nonlinearly—specifically, underweighting high probabilities and overweighting low ones—was famously demonstrated in the Allais Paradox. Over the past two decades, this phenomenon has been well established by a number of behavioral experiments. A number of different probability weighting functions has been proposed that accounts for the existing data. The existence and form of the nonlinearity is important to establish both for theoretical and practical reasons. We explore this question with a combination of data from behavioral experiments and functional brain imaging. Importantly, a number of brain imaging studies have found specific areas in the brain that responds to probabilities. We focus on these brain areas and test whether nonlinearities in the weighting function estimated from behavior is reflected in the brain.

Title: A Neurobiological Derivation of Prospect Theory and Experimental Evidence Over Losses

Authors: Gregory S. Berns, Charles Noussair, C. Monica Capra, Sara Moore, Jonathan Chappelow

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Abstract text (fill no more than this page)

Economists and psychologists have studied decision making under uncertainty extensively. Most studies have focused on decisions in which all outcomes yield non-negative payoffs. However, the study of losses is important because many decisions involve the possibility of a loss. Expected utility theory assumes that the utility of a lottery (p,x), where x is a vector of outcomes and p is the vector of probabilities associated with the outcomes, can be written as $EU(p,x) = \Sigma_j p_j u(x_j)$, where $u(x_j)$ is quasiconcave. Prospect theory assumes that $PTU(x,p) = \Sigma_j w(p_j)v(x_j)$, where $w(p_j)$ is a function that transforms probabilities and $v(x_j)$ is a function that assigns values to outcomes, where $w(p_j)$ and $v(x_j)$ satisfy different monotonicity and curvature properties from expected utility theory. Several forms for both $w(p_j)$ and $v(x_j)$ have been proposed with varying experimental evidence.

Here, we propose a neurobiological origin for both $w(p_j)$ and $v(x_j)$. We assume that both functions derive from biological processes in the brain, which themselves are subject to known chemical constraints. The value function is derived from the Michaelis-Menten kinetics of enzyme-mediated reactions. Assuming these rate-limiting kinetics, we show how a functional form of $w(p_j)$ can be derived based on a "neurobiological certainty equivalent ratio."

While subjects underwent fMRI, we tested this theory over the domain of losses using cutaneous electric shock as the outcome of a series of lotteries with different probabilities. Participants (N=37) were presented with passive lotteries with probabilities of a shock ranging from 1/6 to 1, and varying magnitudes of voltage (between 10% and 90% of maximum tolerable voltage). Subsequently, participants were presented with a series of forced-choices over lotteries with different probabilities and magnitudes of the outcome variable, receiving the appropriate shock with the stated probability after each choice. Using both fMRI and SCR measurements during the passive procedure, we found that the neurobiological certainty equivalent of a lottery in key regions, including the caudate, parietal cortex and dorsolateral prefrontal cortex, correlated with subsequent decisions over a forced-choice of different lotteries. Activation during the passive expectation was used to derive the neurobiological certainty equivalent, which demonstrated different forms for $w(p_j)$ across individuals.

Saturday, September 9, 2006

Session I
Time

10:00 – 10:30 am	Chess Stetson	Reward timing is a special case of event timing: Evidence from the basal ganglia	University of Texas
10:35 – 11:05 am	Kenway Louie	Temporal discounting activity in monkey parietal neurons during intertemporal choice	New York University
11:10 – 11:40 am	Ching-Hung Lin	Medial prefrontal activities represent immediate monetary outcomes in the Soochow Gambling Task: A Near-infrared Ray combined EEG study	National Yang-Ming University
11:45 – 12:15 am	Thomas Campbell	The neurobiology of intertemporal choice	University of Oxford

Session II
Marketing

1:30 – 2:00 pm	Vasily Klucharev	Brain mechanisms of persuasion: fMRI study of persuasive nature of advertising	Erasmus University, Radboud University, Nijmegen
2:05 – 2:35 pm	Brian Knutson	Neural predictors of purchases	Stanford University

Session III
Learning

2:40 – 3:10 pm	Paul Phillips	Subsecond dopamine release during economic decision making in rodents	University of Washington
3:15 – 3:45 pm	Daniela Schiller	Learning by doing—Actions reinforced by fear termination	New York University

Title: **Reward timing is a special case of event timing: evidence from the basal ganglia**

Authors: **C. Stetson, X. Cui, R. Montague, D.M. Eagleman**

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Abstract text (fill no more than this page)

Dopaminergic neurons in the striatum can encode the time of reward (Schultz, Dayan, Montague 1997). This fact is evidenced, for example, by a decrease in their firing rate at the time of the expected reward if it is not delivered (Hollerman and Schultz, 1998). Recently, these same regions of the striatum have been implicated in timing judgments performed in the absence of reward delivery (e.g., Coull et al 1999). We here propose a framework for the role of the striatum in both types of experiments. In fMRI experiments, we find a bilateral region of the ventral striatum which appears to encode temporal order of a motor act and sensory events. This area is most active if the sensory event follows the motor act (implying causality), and less active if the sensory event precedes. This differential activity implies a role for the ventral striatum in encoding the timing relationships between motor outputs and the (necessarily delayed) sensory feedback. We extend the temporal difference algorithm to address not only reward timing, but also the timing between motor actions and sensory feedback. This model extends the role of the midbrain dopamine systems beyond reward error prediction, suggesting reward timing as a special case of more general timing systems. This interpretation of striatal activity ties together temporal judgments with value, offering a computational substrate for interpreting recent findings in temporal discounting in the delivery of reward or pain.

Title: Temporal discounting activity in monkey parietal neurons during intertemporal choice

Authors: Kenway Louie and Paul Glimcher

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Abstract text (fill no more than this page)

Decision-making requires the integration of sensory information and prior knowledge, possibly into a value map of potential actions, before a single action can be chosen. During decision-making in macaques, the activity of saccade-related neurons in the lateral intraparietal area (LIP) represents reward-related information such as reward magnitude and probability of reinforcement, variables which influence the values of saccades. If LIP activity represents all the information guiding a decision, LIP neurons should encode the total subjective, rather than objective, value of saccades and should be influenced by all factors which can influence action selection. One such factor crucial in decision-making is the temporal relationship between action and reinforcement. For both humans and animals, the subjective value of a reward is a decreasing function of the delay to reinforcement, a phenomenon known as *temporal discounting*.

We investigated the activity of LIP neurons in monkeys performing an *intertemporal choice task*. In each trial, animals chose between a smaller immediate reward and a larger delayed reward. Across trials, we varied the delay to the larger reward. We found that monkeys exhibit consistent temporal discounting behavior, choosing the larger reward at short delays and the immediate reward at long delays. Preference data from different magnitudes of delayed reward were used to generate a discount function. Fit with a standard hyperbolic discount model, these data show that monkeys discount the value of rewards as delays increase, with rates of discounting intermediate between the faster rates of pigeons and rats and the slower ones reported in humans. In area LIP, we found that the activity of neurons is consistently modulated by the delay to reward: firing rate is a decreasing function of delay. Moreover, the behavioral discount curve and the average neuronal discount curve are essentially a perfect match early in the trial, immediately after visual target onset. In contrast, late in the trial, activity is much more strongly correlated with the choice of saccade. These results suggest that LIP neurons encode time-discounted subjective value early in the decision process, and shift, during action selection, to encode the upcoming saccade.

Title: **Medial prefrontal activities represent immediate monetary outcomes in the Soochow Gambling Task: A Near-infrared Ray combined EEG study**

Authors: [1]Ching-Hung Lin, [2]Yao-Chu Chiu, Chi-Hsun Wu, Po-Lei Lee, Jen-Chuen Hsieh

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Abstract text (fill no more than this page)

Researchers using the Iowa Gambling Task (IGT) have frequently suggested that the medial prefrontal cortex (MFC) has an important role in integrating somatic signals for making beneficial decision under uncertainty, namely, normal subjects are "foresighted" and sensitive to long-term outcome in the IGT. However, a research group (Chiu et al., 2005) proposed the Soochow Gambling Task (SGT) to demonstrate that a confounding exists in the IGT. They showed that subjects are "myopic" to long-term outcome and are guided by immediate gain. The SGT and IGT have the same degree of uncertainty and structure for long-term outcome. The SGT conclusion of subjects are "myopic" is opposite to that obtained by the Iowa group. However, research has empirically documented that the link between decision-maker choice in SGT and neural activation of the MFC is scant. The study explores whether how subjects choose a preference and their brain activation in the MFC is related. On the other hand, most relevant gambling studies utilized fMRI to probe the related brain function recently. However, due to a shortage of the signal-loss of Blood Oxygen Level Dependence (BOLD) in ventro-MFC areas in most fMRI studies, this study utilized near-infrared ray (NIR) combined with an electroencephalogram (EEG) to overcome the problem of fMRI signal-loss on ventro-MFC region and achieve better time-resolution for probing MFC function. Ten healthy subjects (5 males and 5 females; age range, 19-28 years) participated in the SGT study. Electrophysiological activity and concentration changes in oxygen and deoxygenated hemoglobin over MFC were concurrently monitored via an EEG and NIR instruments. The EEG signals were acquired from 40-electrodes in an EEG cap which is coordinated to a standard EEG 3D head-surface space, namely the 10-20 system. The acquired optical signal was collected by a photomultiplier tube via a detector fiber placed on the subject's forehead. Behavioral results confirmed again that normal subjects were myopic in the SGT. Most subjects preferred frequent gain choices rather than choices with advantageous long-term outcome. The present NIR data showed that the MFC activation (oxygen hemoglobin) is correlated to the "consequence" of gains and losses, and not "anticipation". Obviously, NIR combined behavioral result pointed out that the subjects make decisions with an "immediate" prospective, not "long-term" integration. Notably, based on behavioral and NIR data, activation of the MFC is not correlated with "prediction" of choice, but rather "outcome" of choice under uncertainty. The EEG data acquired a noisy signal pattern that can be contaminated by serious eye-saccade (movement) potential in the task. To conclude, this NIR result which indicated the MFC represented the immediate outcome of choice further confirm the finding on behavioral level in SGT, in addition to providing neuroeconomics with an alternative viewpoint which is different from IGT of how MFC function in terms of monetary gain-loss relates to subject choice patterns.

Title: The neurobiology of intertemporal choice

Authors: Thomas G. Campbell, Tim Preston, Peter Rudebeck, Stephen McHugh, Matthew Rushworth, Nicholas Rawlins, and David Bannerman.

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Abstract text (fill no more than this page)

Intertemporal choices involve decisions between costs and benefits that will occur at different times. Usually agents have to decide between an earlier, smaller reward and a larger, delayed reward. The neurobiology of intertemporal choice is poorly understood.

Rawlins, Feldon and Butt (1985) demonstrated that aspiration lesions of the hippocampus (HPC) cause rats to show impulsive choice on an intertemporal choice task. In a bid to identify more specifically the contributions of the HPC to intertemporal choice we designed a series of experiments in which rats were trained to associate on arm of a T-maze with a small, immediate reward (2 pellets, the LR) and the other arm with a large, delayed reward (10 pellets, the HR). After training, rats were given fibre sparing cytotoxic lesions to the complete HPC, the dorsal half of HPC, the ventral half of the HPC, or sham lesions. Complete hippocampal lesions caused animals significantly to shift their preference to the LR arm. Partial lesions caused a smaller shift of preference to the LR arm, which was significant only in the ventral HPC lesion group. In a second experiment a delay was introduced into the LR arm such that in both the LR arm and the HR arm reward was delayed by 10 seconds. Introducing a delay into the LR arm caused all animals to shift their preference to the HR arm. All surgical groups performed indistinguishably from shams. We have demonstrated that complete lesions of the HPC or lesions of the ventral half of the HPC cause animals to increase their preference for the small, immediate reward in an intertemporal choice task. In addition we have shown that animals with hippocampal lesions are perfectly able to choose between a small and a large reward when both are delayed. This demonstrates that the impulsive choice is not due to a simple mnemonic or spatial deficit. These results challenge traditional theories of hippocampal function. We are currently developing new variants of this task to further characterize the neurobiology of intertemporal choice, and in particular the role of the hippocampus.

Title: **Brain mechanisms of persuasion**

fMRI study of persuasive nature of advertising

Authors: Vasily Klucharev[ab] , Ale Smidts[a] and Guillen Fernandez[b] ,

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Abstract text (fill no more than this page)

Human social and economic decisions are strongly affected by various forms of persuasion. Advertising is a particular type of persuasive communication effectively changing consumers' attitudes and behavior. One of the most powerful techniques of persuasion is that of high expertise or authority often referred to as "expert power". Everyone has seen advertisements where "the dentist recommends..." We studied the modulation of attitudes (buying intention) and memory for the products by perceived presenter's expertise. During fMRI session, we presented 24 female subjects with photos of everyday products following those of celebrities. We found a vivid behavioral effect of the experts on the memory and buying intention for the product. Observed behavioral effects lasted at least 24 hours despite the fact that products were presented only once. Significant interaction of presenters' expertise with buying intention for products was found at dorsal caudate nucleus. Our data suggest that persuasive social context (e.g., communicator expertise) modulates activity of caudate nucleus also known to be implemented in learning, emotional evaluation of outcomes, and trustful behavior. Moreover, we found that experts enhance activity of medial temporal lobe and functionally related cortical areas and consequently improve the memory for presented products. Overall our data suggest that persuasive communication effectively modulates the activity in neural networks involved into trustful behavior and memory encoding that in turn dramatically modulate human economic behavior.

Title: Neural Predictors of Purchases

Authors: Brian Knutson, Scott Rick, G. Elliott Wimmer, Drazen Prelec, George Loewenstein

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Abstract text (fill no more than this page)

Microeconomic theory maintains that purchases are driven by a combination of consumer preference and price. Using event-related FMRI, we investigated how people weight these factors to make purchasing decisions. Consistent with neuroimaging evidence that distinct circuits anticipate benefits and costs, prior to the purchase decision, product preference activated the nucleus accumbes (NAcc), while reduced prices activated the mesial prefrontal cortex (MPFC) and deactivated the insula. Activity from each of these regions predicted immediately subsequent purchases, above and beyond self-report variables. These findings suggest that activity of distinct brain regions related to anticipatory affect precedes and supports consumer purchasing.

Title: Subsecond dopamine release during economic decision making in rodents

Authors: Mark E. Walton[1,2], Jerylin O. Gan[3], Sheena D. Barnes[2], Scott B. Evans[2] & Paul E. M. Phillips[2,3,4]

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Abstract text (fill no more than this page)

Throughout our lives we are constantly assessing the costs and benefits of possible future outcomes of our actions and using this information to guide behavior. There is accumulating evidence that dopamine may contribute to a fundamental component of this process: how rewards are compared with the costs incurred when obtaining them. It has been established that depletion or antagonism of dopamine in the nucleus accumbens is sufficient to lower the physical effort rats will make to obtain greater rewards. Similarly, rats will not tolerate time delays to gain larger rewards following systemic dopamine antagonism. These data suggest that one role of dopamine transmission is to overcome response costs in obtaining rewards. Dopamine neurons are phasically activated on presentation of predictors of future rewards; and this subsecond activity encodes the (average) expected reward. We suggest that this transient activity should produce psychomotor activation to energize proximal behaviors and in this way surmount larger response costs when better rewards are expected. This simple computation should facilitate appropriate action selection either when single reward options or concurrent choices are available. In order to test this hypothesis, we have established a series of operant decision-making tasks in rodents that allow us to assess cost-benefit analysis and normalize across different costs. Using fast-scan cyclic voltammetry we can measure subsecond dopamine transmission in dopamine terminal regions implicated in action selection while rats engage in these tasks. Our first studies examine the effect of obtaining food rewards when physical-effort response costs are imposed.

After four to six weeks of training animals exhibited robust and predictable behavior. Rats consistently chose the option that required fewer lever presses when the outcome on two concurrent-choice levers was the same. Likewise when the response requirement of each lever was the same, rats chose the lever that yielded the largest bounty. As the response requirement for a larger reward option was increased across sessions, animals chose that option less frequently. Moreover, if the response requirement was subsequently lowered again, rats reverted to their former level of performance for that requirement. The behavior was also pharmacologically validated to confirm that it was regulated similarly to other effort-based tasks (e.g., T-maze effort-based decision making). The effect of dopamine-receptor antagonists were tested in a behavioral session on animals that had achieved stationary behavior between the three previous sessions where a high reward outcome (4 pellets) was available for 24 lever presses with a concurrent low-reward (2 pellets) choice for 4 presses. These drugs changed response allocations so that animals chose the high reward option less frequently. However, they did not significantly alter performance when that option was presented alone.

Our preliminary voltammetric data suggest that while the amplitude of subsecond dopamine release in the nucleus accumbens encodes the expected reward magnitude it does not appear to be modified by the response requirement of the outcome. This encoding of the expected absolute reward value rather than its net utility after it has been discounted by response costs provides a useful signal for generating appropriate cost thresholds for response allocation.

Title: Learning by Doing – Actions Reinforced by Fear Termination

Authors: Daniela Schiller (1,2), Christopher K Cain (1), Kate Kuhlman (2), Joseph E LeDoux (1) and Elizabeth A Phelps (1,2)

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Abstract text (fill no more than this page)

Animals and people do not merely react to fear-eliciting stimuli, they are also motivated to take action in order to escape and avoid these stimuli. Animal studies have shown that passive or pavlovian fear reactions, such as freezing, are mediated via a pathway between the amygdala and the brainstem. It is hypothesized that active or instrumental responses, such as reactions that terminate fear-eliciting stimuli requires a pathway between the amygdala and motor circuits in the ventral striatum. Interestingly, such responses can be learned in the absence of a primary reinforcer (e.g. electric shock), suggesting that the termination of fear itself may serve as a reinforcer for action learning.

In the present study, we developed a novel procedure to study escape from fear (EFF) learning in humans. Subjects were presented with either fear-eliciting or neutral images. A few seconds after the image presentation, a colored frame appeared around the image. The subjects were instructed to press a button whenever they observed the colored frame. The frames appeared in one of two colors (e.g. blue or yellow). For each color, the button press had a different outcome – either the image presentation was terminated (escape outcome), or the image remained for an additional two seconds (non-escape outcome). Galvanic skin responses (GSRs) to the images served as an index of fear and button-press reaction time served as the dependent measure for EFF learning.

GSRs were greater to the fear-eliciting images than to the neutral images, confirming the negatively arousing effect of these images. Reaction time measurements of the button press to the colored frames showed no difference between the escapable and non-escapable neutral images. In contrast, reaction times to the escapable fear-eliciting stimuli were faster than responses to the non-escapable images, suggesting that EFF learning was successful. Interestingly, reaction times to the escapable fear-eliciting stimuli were similar to those associated with the neutral images.

Consistent with previous findings, our results suggest that negatively loaded affective stimuli lead to slower reactions and to a tendency to dwell longer before responding. They also show that this negative emotional bias was abolished when the response was reinforced by the elimination of the aversive stimuli. These results support the notion that humans can learn an instrumental EFF response with fear-termination as the reinforcer.

We are currently investigating brain areas involved in the shift from passive fear to active coping in the human brain using fMRI. In particular, we are interested in looking into the role of amygdala-striatal interactions in using fear termination as a reinforcer to guide actions, as well as to examine whether fear-termination and appetitive reinforcers recruit similar brain systems to guide behavior.

Support: Fulbright award to DS and NIMH grants to JEL and EAP

Sunday, September 10, 2006

Session I
Choice

9:00 – 9:30 am	Camillo Padoa-Schioppa	Neurons in orbitofrontal cortex encode economic value independently of the "menu"	Harvard Medical School
9:35 – 10:05 am	Adam Kepecs	Rats under uncertainty: Orbitofrontal neurons support updating of decision strategy	Cold Spring Harbor Laboratory
10:10 – 10:40 am	Ryan Jessup	Decision field theory as a bridge between neural models and complex decision making behavior	Indiana University

Session II
Sociality

11:15 – 11:45 am	Paul Zak	An fMRI study of trust with exogenous oxytocin infusion	Claremont Graduate University
11:50 – 12:20 pm	Frank Krueger	The neural basis of economic decision-making in two-players' reciprocal trust games	NIH/NINDS
12:25 – 12:55 pm	William Harbaugh	The neural basis of charitable giving	University of Oregon

Title: Neurons in orbitofrontal cortex encode economic value independently of the "menu"

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Abstract text (fill no more than this page)

In a recent study, we found that individual neurons in orbitofrontal cortex (OFC) encode the subjective value monkeys assign to different beverages when they choose between them. In these experiments, monkeys chose between two juices. When juices were offered in equal amounts, monkeys chose the preferred one, but if the less preferred juice was offered in sufficiently large amount, monkeys would choose it. The relative value of the two juices was inferred from the indifference point. We found that neurons in OFC encode three variables: the `offer value` (i.e., the value of one or the other of the offered juices), the `chosen value` (i.e., the value of the chosen juice, independently of its type and quantity), and the `taste` of the chosen juice. The time course corresponded well to the mental processes monkeys presumably undertake during the trial, with responses encoding the offer value most prevalent immediately after the offer was presented to the animal.

In the present study we explore whether the activity of value-encoding OFC neurons depends on the "menu" offered to the animal. In this experiment, we employ in each session three juices (A, B and C, in decreasing order of preference). In each trial, the monkey chooses between two juices, and trials with the three pairs A:B, B:C and C:A are intermixed. Behaviorally, we observe that the relative values of the three pairs combine according to transitivity. For example, in a representative session, we measure V(1A)~V(2B), V(1B)~V(2C), and V(1A)~V(4C). Assuming linear value functions, we put different quantities of the three juices on a common value scale. Preliminary analyses of 376 OFC neurons indicate that in the large majority of cases their responses do not depend on the "menu." For example, the activity of neurons encoding the `value of A offered` varies with the amount of juice A available, but does not depend on whether juice A is offered against juice B (A:B trials) or against juice C (C:A trials). Similarly, the activity of neurons encoding the `chosen value` varies with the value chosen by the monkey, but does not depend on the pair of juices offered in the trial (A:B, B:C, or C:A). Finally, `taste` responses do not depend on the other type of juice offered in the same trial.

It is interesting to discuss these data conjointly with the results previously reported by Tremblay and Schultz (T&S), who delivered to monkeys one of three types of juice (A, B and C, in decreasing order of preference) in fixed amount. In their experiment, trials were blocked, with only one pair of juices employed in each block. T&S found in OFC neurons that responded to juice A but not to juice B during "A:B" blocks, and to juice B but not to juice C in "B:C" blocks. Taken alone, their result is open to several interpretations. For example, their neurons might encode juice `preference` (i.e., the ordinal ranking). Alternatively, their neurons might encode the `relative value` of the two juices (i.e., the value ratio or the value weight). Our first experiment rules out both these possibilities, because neurons encoding the `offer value` and the `chosen value` do so independently of the value of the other juice offered in the same trial. Similarly, the present data obtained with three juices seem to argue against the alternative hypothesis that OFC neurons might encode value in a "menu-dependent" way. An intriguing possibility is that the results of T&S critically depended on the fact that trials were blocked, suggesting that the activity of OFC neurons might vary depending on the broader context. However, further work is necessary to test this hypothesis directly.

Title: Rats under uncertainty: Orbitofrontal neurons support updating of decision strategy

Authors: Adam Kepecs, Naoshige Uchida and Zachary Mainen

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Abstract text (fill no more than this page)

Uncertainties during decision making may arise due to a variety of factors yet most of our understanding comes from the study of risk alone or contrasted with ambiguity. Here, we examined uncertainty during category decisions, where the lack of knowledge about the category boundary limits choice accuracy. Importantly, estimating uncertainty during categorization can be beneficial to guide the learning process and thereby improve future decisions.

We pursued these ideas in rats by investigating the neural representation and the behavioral impact of uncertainty during an odor-mixture categorization task. Rats were trained to report the category of different mixtures of odors "A" and "B" and were rewarded either at the left or the right choice ports for correct decisions. This is akin to asking a human whether a particular blend of blue and green colors is more blue or more green. For color blends in the middle, the answer depends on an arbitrary convention of color categories, creating uncertainty about decisions. Similarly, our training protocol enforced an arbitrary boundary between odor categories. Note that this task allowed us to systematically manipulate the ambiguity of individual decisions by varying odor mixture ratios and hence changing the distance of the stimulus from the category boundary.

To explore the neural representation underlying decision uncertainty, we recorded neural activity from the orbitofrontal cortex, a prefrontal region known to be activated during choice behaviors involving uncertainty in humans. What should a representation of uncertainty look like? Uncertainty should vary with the distance between the odor stimulus and the imposed category boundary, a variable that is under experimental control. However, since the task involves ambiguity, we do not have direct access to the other key variable necessary for estimating uncertainty: the rat's internal knowledge about the category boundary. But a *correct* estimate of uncertainty should vary with accuracy, since more uncertainty implies worse performance. Using these criteria for uncertainty encoding, we focused our analysis on the reward anticipation period after the choice was made but before reward feedback was provided. We found that many orbitofrontal neurons signaled uncertainty. The majority of these increased their firing rate with growing uncertainty, while fewer neurons decreased their firing during more uncertain decisions and these were also less selective.

Next we examined if uncertainty actually contributed to decisions made by the rats on a trial to trial basis. In order to benefit from an estimate of uncertainty behaviorally, statistical learning theory predicts that the rate of learning should be proportional to uncertainty. Consistent with this, we observed that rats biased their decisions based on the combination of the uncertainty associated with the previous decision and trial outcome, as if they were using uncertainty and reward to update the category boundary. In summary, our results demonstrate that rats possess a neural representation of uncertainty associated with their decisions and ongoing adjustments in behavior depend on the magnitude of this variable.

Title: Decision Field Theory as a Bridge Between Neural Models and Complex Decision Making Behavior

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Abstract text (fill no more than this page)

Diffusion processes, and their discrete time counterparts, random walk models, have demonstrated an ability to account for a wide range of findings from behavioral decision making for which the purely algebraic and deterministic models often used in economics and psychology cannot account. Recent studies that record neural activations in non-human primates during perceptual decision making tasks have revealed that neural firing rates closely mimic the accumulation of preference theorized by behaviorally-derived diffusion models of decision making (Gold & Shadlen, 2001, 2002).

Here we present decision field theory (Busemeyer & Townsend, 1993), a connectionist model of decision making that implements diffusion processes, as a bridge linking lower-level neural recordings and more complex behavioral findings from psychology and economics. Essential neural correlates of this model include a basal ganglia network of lateral inhibition and orbitofrontal reward representations (see Frank & Claus, 2006, for a similar proposal) connected via parallel circuits (Alexander, DeLong, & Strick, 1986).

Title: An fMRI study of trust with exogenous oxytocin infusion

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Abstract text (fill no more than this page)

The neuroactive hormone oxytocin (OT) has recently been shown to facilitate interpersonal trust (Zak et al., 2004, 2005; Kosfeld et al., 2005), but the neural substrates associated with OT infusion that affect trusting behaviors are not well understood. This paper presents fMRI data showing that brain regions rich in OT receptors (OTRs) are more active when trusting a human being than when choosing monetary transfers with a computer. In addition, intranasal OT infusion is shown to scale the BOLD signal in ROIs with OTRs relative to subjects given a placebo. While OTRs are distributed throughout the brain, we do not find that other cognitive functions are affected by intranasal OT. We conclude that decisions involving interpersonal trust depend strongly on several brain regions dense with OTRs.

Title: The neural basis of economic decision-making in two-players' reciprocal trust games

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Abstract text (fill no more than this page)

An element of trust characterizes almost all human social interactions. Recent evidence indicates that trust and cooperation play a key role in economic decision-making. Previous studies used single or multi-shot interactions, in which players maintain their roles throughout the games. In real life, however, people often alternate their roles in economics environments while interacting with the same person over a longer period of time. We employed event-related fMRI while two strangers (22 males and 22 females, age: 28.3 years old) interacted with on another each in a separate MRI scanner. Paired participants played multi-shot reciprocal trust games in alternating roles as decision maker 1 (DM1) and decision maker 2 (DM2). In reciprocal trust games, DM1 can end the game by non-trusting DM2 and both players receive a small payoff, or DM1 can continue the game by trusting DM2, so both receive a moderate payoff. DM2 can reciprocate DM1's trust for a moderate payoff or defect DM1' trust for a large payoff. The experimental design allowed us to address the question of which brain regions modulate prosocial (decisions to trust and to reciprocate) and selfish (decisions to non-trust and to defect) behavior in humans. Our results showed that limbic, orbitofrontal, and anterior prefrontal regions were recruited during prosocial and selfish decision-making. All decisions engaged the paracingulate cortex, a region with the ability to represent another person's psychological perspective to predict the behavior of others. Prosocial decisions engaged the hypothalamus, ventral striatum (Nucleus accumbens), and subgenual cortex, a network of regions that is linked with social attachment. Further, prosocial decisions activated the medial orbitofrontal cortex, whereas selfish decisions engaged the lateral orbitofrontal cortex. This result is in agreement with the medial to lateral functional specialization of the orbitofrontal cortex in representing reward and punishment associations, respectively. Decisions to trust in comparison to decisions to reciprocate engaged the frontopolar cortex (BA10). In contrast, decisions to defect in comparison to decisions not to trust activated the dorsal medial prefontal cortex (BA9). Both regions are involved in representing the long term value of future outcomes of one's decisions. In conclusion, our findings indicate that economic decision-making relies on primitive neural systems of social attachment and aversion, engaged by prosocial and selfish decisions. In addition, the more recently evolved anterior prefrontal regions are recruited by prospective evaluation of choice outcomes.

Title: The neural basis of charitable giving.

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Abstract text (fill no more than this page)

Economic models of altruistic behavior propose that people get a direct utility benefit, or "warm glow" from making charitable contributions. If we assume that gifts to charity produce utility benefits we can explain many aspects of charitable giving, such as responses to changes in wealth and taxation, using standard models of utility maximization.

In this paper we use FMRI to map out how the brain activates in response to changes in the amount of money that people give to charity (a local food bank), and we compare that with activation when people get money for themselves. We collected data from 20 female subjects. The amounts at stake were approximately $100. Within subjects, we varied whether transfers from the subjects to the charity were mandatory or voluntary, and we varied the price of giving money to the charity.

The results demonstrate that activation in the mid brain when people give money to the charity is quite similar to the pattern of activation when they get money. We also show that when people must make decisions about whether or not to give money to a charity, we find activation in pre-frontal cortex areas that are associated with decision-making in general. Furthermore, when the decisions that people must make are more difficult, in the sense that the gain to the charity is close to the cost to the giver, activations in these decision-making areas are larger.