Society For Neuroeconomics

3rd Annual Meeting

September 15-18 2005

Kiawah Island, South Carolina

Thursday, September 15, 2005

Workshop I: Neuroscience for Economists

Part 1

1:30 -3:00 pm **Souheil Inati: And Introduction to The Physics of fMRI**

Magnetic Resonance Imaging is a wonderful technique to study the human brain non-invasively and the growth of functional MRI over the last fifteen years has been astounding. I will present an introduction to the physics of MRI in the context of neuroscience.

I will start from the basic physics of magnetic resonance and then proceed through image acquisition and the inner workings of an MRI scanner. From there, I will move to a discussion of the BOLD effect (the physiological basis of the signals measured in an FMRI experiment) and briefly touch on the various sources of noise inherent in the technique.

Time permitting, I will discuss some MRI methods that, although probably unfamiliar to most cognitive scientists, are likely to have a big impact on their research in the near future: spectroscopy, perfusion, and diffusion.

Recommended Readings:
Chapters 3, 4, and 7 of Huettel, Song, & McCarthy, Functional Magnetic Resonance Imaging, Sinauer, 2004

Part 2

3:15 – 4:45 pm Scott Huettel: fMRI Data Analysis

This workshop will cover the central goals, techniques, and limitations of fMRI experimental design and data analysis. Its emphasis will be conceptual rather than methodological, focusing on how to create good designs and select appropriate analyses, not how to use particular analysis packages. Key topics will include matching experimental designs to the physiological processes of interest in the brain, understanding and avoiding common errors in design analysis, and interpreting (but not overinterpreting) experimental results.

Recommended Readings:

Brett, M., Johnsrude, I. S. & Owen, A. M. The problem of functional localization in the human brain. Nat Rev Neurosci 3, 243-9 (2002).

The following text book will also be referred to extensively:

Huettel, S.A., Song, A.W., & McCarthy, G. (2004). Functional Magnetic Resonance Imaging. Sunderland, Massachusetts: Sinauer Associates.

Workshop II: Economics for Neuroscientists

Part 1

1:30 -3:00 pm Colin Camerer: Choice Theories Under Risk

In economics, choice theory has largely developed through systems of axioms which imply mathematical forms of "preferences". For example, if a person can choose between any two goods, and choices are transitive, then those choices can be "represented" by a numerical function assigning a real number to each good (a "utility") and higher-numbered goods are preferred. When goods have various outcomes (choices are "uncertain") many axiomatic systems have been proposed as accounts of behavior. The most well-known is "expected utility" (EU)-the itility of gamble G, which has outcomes x with associated probabilities p(x), is ?x u(x)p(x). EU follows from a "cancellation" or "independence axiom" which assumes that in choosing between gambles, people cancel out any common outcomes x with common probability p(x), and choose on the basis of distinctive outcomes only. Probabilities can also be based on subjective or "personal" intuitions rather than relative frequency "leading to SEU). Many other theories (called "non-EU") follow from weakening the independence axiom in various ways. An important one is "prospect theory": Prospect theory assumes that the domain of value is changes from a reference point r, people are averse to "loss" (x<r) relative to gain, and probabilities are weighted nonlinearly by a function ?(p).

Most of these theories were originally derived from logic, informed casually by self-reported "plausibility", rather than from empirical evidence. Many experiments have been run in recent years, which tend to support prospect theory, although when fitting individual-level parameters it is often difficult to improve on EU (which remails the theory most often used in applications to analysis of markets like insurance and stocks). Animal experiments with food and juice rewards generally suggest behavior close to that of humans.

Some theorists have also begun to explore what type of decision rules would have evolved, mathematically. The tentative lesion is that principles which are logically appealing (such as cancellation) are not necessarily evolutionarily adaptive. Choice theory is a rich cornucopia of theories for neuroscientists to think about.

Recommended Readings:

Camerer, Colin. "Individual Decision Making", in Handbook of Experimental Economics (Editors Kagel and Roth), Princeton Univ Press 1995. (long)

Glimcher, Paul and Aldo Rustichini. "Neuroeconomics: The consilience of brain and decision". Science, 2004.

Starmer, Chris. "Developments in non-expected utility theory: the hunt for a descriptive theory of choice under risk". J Economic Literature, 2000.

Part 2

3:15 - 4:45 pm **Eric Johnson: Behavioral Economics and Decision-Making**

This workshop will focus on several areas, discussing major theoretical frameworks and empirical results. The emphasis is on what is most relevant for empirical studies, and on the psychological processes that generate the kinds of results we see in behavioral economics.

These areas and some topics will be:

Valuation: Relative evaluation and Loss Aversion. Issues in measuring preferences, a constructive view of preferences. Illustrations from both laboratory and field experiments.

Uncertainty: The weighting function and Cumulative Prospect Theory. Differences between experienced and stated probabilities.

Representation: How to people represent and encode choices and outcomes. Mental Accounting and narrow bracketing. Framing.

Choice over time: Four stylized facts and recent results in the psychology of intertemporal choice.

Strategic Interaction: The roles of fairness and limited cognition. Learning.

Recommended Readings:

Kahneman, D., & Tversky, A. (Eds.). (2000). *Choices, values, and frames*: New York, NY, US: Cambridge University Press. Contains many of the papers below.

Valuation:

Tversky, A., & Kahneman, D. (1991). Loss Aversion in Riskless Choice - a Reference-Dependent Model. *Quarterly Journal of Economics, 106*(4), 1039-1061.

Payne, J. W., Bettman, J. R., & Johnson, E. J. (1992). Behavioral decision research: A constructive processing perspective. *Annual Review of Psychology, 43*, 87-131.

Uncertainty:

Tversky, A., & Kahneman, D. (1992). Advances in Prospect Theory: Cumulative Representation of Uncertainty. *Journal of Risk and Uncertainty, 5*, 297-323.

Wu, G., Zhang, J., & Gonzalez, R. (2004). Decision under Risk. In N. Harvey & D. Kohler (Eds.), *Blackwell Handbook of Judgment and Decision Making*. London: Blackwell.

Representation:

Thaler, R. H. (1999). Mental accounting matters. *Journal of Behavioral Decision Making, 12*(3), 183-206.

Johnson, E. J., & Goldstein, D. (2003). Do defaults save lives? *Science, 302*(5649), 1338-1339.

Choice over Time:

Frederick, S., Loewenstein, G., & O'Donoghue, T. (2002). Time discounting and time preference: A critical review. *Journal of Economic Literature, XL*, 351-401.

Strategic Interaction:

Camerer, C. F. (2002). *Behavioral Game Theory*: Princeton University Press.

Friday, September 16, 2005

Morning session, chaired by Eric Johnson

Choice Amongst Lotteries: Cognition and Discounting

8:45 – 9:15 am	Samuel McClure	Neural mechanisms of time discounting for primary rewards	Princeton University
9:15 – 9:45 am	Julian Jamison	Discounting: fMRI looks into the future	University of California
9:45 – 10:15 am	Paul Glimcher	Neural mechanisms of temporal discounting in humans	New York University
10:15 – 10:30 am	Coffee Break		
10:30 – 11:00 am	Ching-Hung Lin	Immediate gain is long-term loss: Are there foresighted decision makers in Iowa gambling task?	National Yang-Ming University
11:00 – 11:30 am	John Dickhaut	The role of differential outcome feedback on transitivity, heart rate, galvanic skin response and fMri.	University of Minnesota
11:30 – 12:00 pm	David Eagleman	When is regret advantageous in decision making?	University of Texas
12:00 - 12:30 pm	Discussion		

Title: **Neural mechanisms of time discounting for primary rewards**

Authors: Samuel M. McClure[1], David I. Laibson[2,3], George Loewenstein[4], Keith Ericson[3], Kimberlee D. McClure[5], Jonathan D. Cohen[1,6]

Institution: [1] Department of Psychology, and Center for the Study of Brain, Mind, and Behavior, Princeton University, Princeton, NJ 08544; [2] Department of Economics, Harvard University, Cambridge, MA 02138; [3] National Bureau for Economic Research, Cambridge, MA 02138; [4] Department of Social and Decision Sciences, Carnegie Mellon University, Pittsburgh, PA 15213; [5] Department of Chemistry, Princeton University, Princeton, NJ 08544; [6] Department of Psychiatry, University of Pittsburgh, Pittsburgh, PA 15260

Address: Princeton University, Princeton, NJ 08544

Email: smcclure@princeton.edu

Abstract text (please fill no more than this page)
In previous studies, two brain systems were shown to be involved when people choose between rewards available at different time delays. One system (δ), composed of cortical areas in the frontal and parietal lobes, was activated equally by all intertemporal choice problems independent of the time of reward availability. The second system (β), including brain areas associated with mesolimbic dopamine projections in the ventral striatum and medial prefrontal cortex, was preferentially activated when a reward was available at the earliest possible delay. We replicate and extend these findings using a natural reward, fruit juice, in place of money. This manipulation allowed for a more precise characterization of the time course over which the β and δ systems are activated. We report that the same brain areas are associated with intertemporal decision-making for natural rewards as were previously identified. Furthermore, the β system shows a graded response that varies with reward delay over a time horizon of several minutes.

Title: **Discounting: fMRI Looks Into the Future**

Authors: Jon Wegener; Kristoffer Madsen; Mark Christensen; Julian Jamison*

Institution: Danish Research Centre for Magnetic Resonance, Copenhagen University Hospital; University of California

Address: *Center for Health & Community
3333 California Street, Suite 465
San Francisco, CA 94143-0844
USA

Email: *julison@berkeley.edu

Abstract text (please fill no more than this page)
Individuals make many decisions that involve intertemporal choice, which by definition involve valuing the future relative to the present (or near-term future). These relative valuations vary greatly from one person to another, and the specific functional form of this time discounting has many implications for outcomes ranging from savings behavior to health choices. We address this topic by using functional MRI, extending and refining the pioneering work of McClure, Laibson, Loewenstein, & Cohen (2004). Subjects are offered a variety of monetary amounts at any of six different delay times, and are asked to rate that particular option (thereby focusing their attention). This allows us to unambiguously identify any significant neural correlates of either the time horizon and/or the amount offered, with an initial hypothesis that the limbic system would be implicated. In particular, we test for any areas that show a noticeable graded or parametric relationship to the time delay, and we then test the validity of these findings by using the results to go back and predict the original responses.

Title: **Neural mechanisms of temporal discounting in humans**

Authors: Paul W. Glimcher and Joseph W. Kable

Institution: New York University

Address: 4 Washington Place, Room 809, New York, NY 10003

Email: glimcher@cns.nyu.edu

Abstract text (please fill no more than this page)

When a reward will be received strongly influences the subjective value of that reward, a phenomenon known as temporal discounting. To investigate the neural basis of temporal discounting, we intensively characterized how the subjective value of a monetary reward declines with delay to that reward for individual subjects, using a fairly standard neoclassical paradigm adapted for functional MRI. We then used this characterization to find brain areas where activity is tightly correlated with present value as estimated using this traditional approach.

During behavioral sessions, subjects made repeated choices between receiving an immediate payoff of $20 (which was always fixed so as to maximize the power of our neural analysis) and receiving a variable amount (ranging from $20 to $100) at a variable delay (ranging from 6 hours to 6 months). Subjects were paid according to their choices on four randomly chosen trials per session. All payments were made using commercial debit cards that could automatically be incremented at the time of the payment. This method of payment reduced any transaction costs associated with delayed rewards, and also allowed us to track subjects' consumption of the monetary reward.

For each subject, we estimated the indifference point for each delay--the amount at which the subject preferred $20 now and the larger delayed reward equally. This series of indifference points was used to trace a discount curve, describing how the subjective value of a reward declines with the delay to that reward, for each individual subject. For all subjects tested, the shape of this discount curve was well-characterized by a hyperbolic function, consistent with previous behavioral findings across a range of species. While the discount function within an individual was fairly stable across sessions, the steepness of the discount function varied widely across subjects.

After characterizing the individual discount function for each subject, we then measured neural activity using functional MRI in the same subjects making a similar series of choices. Our preliminary results indicate that neural activity in the ventral striatum, and in some subjects the posterior parietal cortex, was correlated with the present value of the rewards across all of the delays that we examined. Thus, these areas may encode the desirability of a reward, taking into account the time at which that reward will occur. Future studies will examine both the neural inputs to these areas and whether these areas also represent present value when the early reward is presented at different times.

Title: **Immediate gain is long-term loss:**
Are there foresighted decision makers in Iowa gambling task?

Authors: Yao-Chu Chiu, Ching-Hung Lin, Jong-Tsun Huang, Shuyeu Lin, Po-Lei Lee & Jen-Chuen Hsieh

Institution: Institute of Neuroscience, School of Life Science, National Yang-Ming University, Taipei, Taiwan.

Address: Integrated Brain Research Unit, Departement of Medical Research and Education, No. 201, Sec. 2, Shih-Pai Road, Taipei 112, Taiwan

Email: eandy924@ms42.hinet.net

Abstract text (please fill no more than this page)
The studies in behavioral decision making have pointed out that decision makers are often "myopic" to the final outcome. On the contrary, Damasio and Bechara proposed the Somatic Marker Hypothesis (SMH) and then conducted the Iowa Gambling Task (IGT) to demonstrate that decision makers are foresighted, while ventromedial prefrontal (VM) patients' choices are short-sighted to the final outcome. There exists marked discrepancy between these two views. In the IGT, A and B were designated as "bad" decks with lower final outcome (-$ 250 dollars), C and D were "good" decks with higher final outcome (+$ 250 dollars). Normal subjects and VM patients tended to select the "bad" decks roughly in the first 30 card-turning trials (out of 100), yet only normal subjects would gradually shift to the "good" decks and avoided the "bad" decks. A careful examination of the IGT reveals a concealed confounding between final outcome and gain-loss frequency. We argue that final outcome is not the dominant factor in guiding normal individual's preferences. Rather, a notion of gain-loss frequency is proposed to serve as the determining factor. For "bad" decks in the IGT, A contains 5 gains and 5 losses, B contains 9 gains and 1 loss; for "good" decks, C contains 5 gains and 5 standoffs, D contains 9 gains and 1 loss. The "bad" decks contain 14 gains and 6 losses, whereas "good" decks contain 14 gains with only one loss. Both categories comprise the same number of gains. Nonetheless, the number of losses was much lesser in the "good" decks. To differentiate the relative contribution between the final outcome and the gain-loss frequency, we designed a new task, namely, the Soochow Gambling Task (SGT). The SGT contains four decks and each deck contains 5 card-turning trials as a unit, with a total of 100 trials as constrained in the IGT. The "good" decks of SGT will lead to a better final outcome (with 1 gain and 4 losses), while "bad" decks will lead to a worse final outcome (with 4 gains and only 1 loss). Thus, the choice pattern that is based on gain-loss frequency should be different from that of final outcome. The results showed that subjects preferred the "bad" decks (A & B) to the "good" decks (C & D) . This finding supports the prediction based on gain-loss frequency but contrary to that of final outcome. Moreover, the average of the "bad" decks choice was higher than that of the "good" decks right from the beginning. The effect of gain-loss frequency we mentioned is not an isolated finding. Rechecking the "bad" decks A and B in the original IGT showed that "bad" deck B (9 gains and 1 loss) was also chosen more frequently than deck A (5 gains and 5 losses). Similar results were also reported by other research groups. Contrary to the prediction of SMH, our data indicate that normal subjects were explicitly guided by the gain-loss frequency instead of final outcome. The present view, although different from the explanation of SMH, is consistent with the view of the behavioral decision literature that normal individuals are often myopic or short-sighted in decision making.

Title: **The role of differential outcome feedback on transitivity, heart rate, galvanic skin response and fMri.**

Authors: John Dickhaut, Trent Jerde, Baohua Xin, and Aldo Rustichini

Institution: University of Minnesota

Address: 3-113 CarlSMgmnt, 7041, 321 19th Ave. South, Minneapolis, MN 55455

Email: JDICKHAUT@csom.umn.edu

Abstract text (please fill no more than this page)
Many gambles, including those that are played at casinos, afford economic agents the opportunity to observe and learn about the stochastic mechanism that generates state uncertainty and such gambles provide agents with immediate feedback on the outcome of their choices. Recent studies of choice, in particular those using the card deck selection task of Damasio (Damasio, A.R., Tranel, D., Damasio, H., 1991. Somatic Marker and the guidance of behavior:theory and preliminary testing) provide subjects instant outcome information as well as the ability to learn the distribution of cards in the decks being sampled.

In the current design, each subject chooses between gambles and certainty amounts in 3 settings. In setting 1 there is no immediate outcome feedback, in setting two there is immediate outcome feedback and in setting 3 there is no immediate outcome feedback. To examine the somatic marker hypothesis we put particular emphasis on the difference between the outcomes in the first and third condition, which include no outcome feedback. In the third condition after having been through a set of feedback trials the subject in principle will have developed somatic markers for the good and bad outcomes and thus should be able to use them in making the decisions even when the feedback is not present. Thus such markers should facilitate decisions in condition 3 contrasted with condition 1.

Our early results (with GSR) lend support to the conjecture that in these standard gambling choices there is a only a limited role for emotional factors. First there is evidence consistent with the notion that removing feedback and observation of the mechanism can actually lead to no alteration of the quality of decisions. In all conditions the number of transitive choices in the setting with feedback in which increased arousal occurred led to no less transitivity than in the setting with no feedback which produced no comparable arousal.

Indicants of emotion (GSR) are strongest when subjects are making choices in the feedback setting but in fact for most subjects the highest emotional response is during that time that the subjects see the play of the gamble. However when there is not immediate feedback the role of emotions is negligible. We still our analyzing the Heart Rate and fMRI data.

Title: **When is regret advantageous in decision making?**

Authors: David M Eagleman

Institution: University of Texas

Address: 6431 Fannin St, Suite 7046

Email: deagleman@uth.tmc.edu

Abstract text (please fill no more than this page)
Regret is an emotion that accompanies negative outcomes to decisions for which we have been responsible. Given a choice between 2 gambles, subjects will experience regret if the unchosen gamble yields a higher reward than the chosen gamble. However, it remains unclear how evaluative signals like regret are involved in decision-making, and when they are advantageous. To elucidate the how and why of regret, we here appeal to pathologies, behavioral experiments and computational modeling. First, patients with lesions of the orbitofrontal cortex (OFC) appear to experience no regret. A recent report hypothesized that advantageous choice behavior depends on the ability to anticipate and hence minimize regret, and thus OFC patients should have inferior performance (Camille et al, Science, 2004). To the contrary, we have been able to show that anticipated regret is not always helpful, and especially not for gambling tasks (Eagleman, Science, 2005). Instead, emotion can play a disruptive role in gambling tasks, and OFC patients make more rational decisions than normals and hence tend to perform better on gambling tasks (Shiv et al 2005). We have developed a computational model to further elucidate the neural basis of regret in decision making. A good deal of evidence shows that animals use predictive internal models (PIMs) to generate predictions about next states of the world. To explain many features of regret, we have proposed the Many Worlds Algorithm, a model in which predictive models are applied to state-of-the-world data from past decision points, and fictive outcomes (counterfactuals) are generated. These fictive outcomes are compared against actual current values, and the difference translates into regret if the fictive outcome is superior. The regret signal feeds back to modify the predictions of the PIM, and thus to modify the likelihood of choosing that decision the next time. Combining this model, OFC patient data, and behavioral experiments in our lab, we are able to demonstrate that the irreducible uncertainty inherent in most gambling tasks renders regret useless and often disadvantageous. The neural machinery underlying the generation of regret becomes increasingly useful when the world is increasingly stable in its decision-return relationships. In conclusion, we propose a specific neural basis for the experience of regret, and show that this machinery finds itself in a pathologic range during gambling tasks of irreducible uncertainty, since organisms evolved in semi-stable worlds. Therefore, in typical gambling tasks, the adaptive systems underlying regret become disadvantageous.

Friday, September 16, 2005

Afternoon session, chaired by Sam McClure

Constructing Value

1:30 - 2:00 pm	Eric Johnson	Query theory, inhibition, and individual differences in value construction	Columbia University
2:00 - 2:30 pm	Greg Berns	Reward is relative: fMRI and psychobiological evidence	Emory University
2:30 - 3:00 pm	Coffee Break		
3:00 - 3:30 pm	Camillo Padoa-Schioppa	Neurons in orbitofrontal cortex process economic value in abstract	Harvard Medical School
3:30 - 4:00 pm	Michael Platt	Subjective scaling of neuronal activity in macaque parietal and cingulated cortex	Duke University
4:00 – 4:30 pm	Discussion		

Title: **Query Theory, Inhibition, and Individual Differences in Value Construction**

Authors: Eric Johnson, Hannah Bayer, Jeff Brodscholl and Elke Weber

Institution: Columbia University

Address: 3022 Broadway, Graduate School of Business, Uris 514, NY,NY 10027

Email: ejj3@columbia.edu

Abstract text (please fill no more than this page)
Query theory is a cognitive analysis of how people construct value judgments in various domains, in particular assessing degrees of loss aversion and endowment, framing effects and asymmetries in intertemportal choice. The major assumptions of the theory are that when a person answers a question concerning monetary value: (1) they decompose the question into a set of more specific, often opposing, queries, (2) and sequentially perform the queries to construct value. (3) Because of inhibitory processes or output interference similar to those in part list cueing or retrieval induced forgetting, the first query results in a richer represenation that has more impact upon choice, and (4) different response modes (such as selling or choosing, accelerating or delaying consumption) have different characteristic orders of query execution.
According to query theory, individual differences in variables such loss aversion, time preference and anchoring should be correlated with the asymmetry in recall produced as the first query inhibits the second. In this paper, we focus on individual differences variables which affect the ability to shift from one query to another. The focus on inhibition and retrieval induced forgetting suggests three individual difference measures that should have similar effects: The first is age, since age is related to a decline in task switching performance. The second is a measure of cognitive impulsiveness developed by Frederick and shown to influence intertemporal discount rates. The third is nicotine which has been shown to increase levels of retrieval induced fogetting.
We report the results of several large scale studies which show that the pattern of each of these individual difference measures is very similar across these somewhat disparate decision phenomena: For example, older people are more loss averse, show greater discounting and asymmetry in intertemporal choice, and greater degrees of anchoring. Similar results exist for the Frederick Cognitive impulsivity scale and smoking.
We will close by discussing the implications of this for imaging studies.

Title: **Reward is Relative: fMRI and Psychobiological Evidence**

Authors: Rosa-Aurora Chavez-Eakle[1], Jonathan Chappelow[1], Nina Mazar[2], Caroline F. Zink[1], Dan Ariely[2], Gregory S. Berns[1]

Institution: [1]Emory University & [2]MIT

Address: 101 Woodruff Circle, Suite 4000, Atlanta, GA 30322

Email: gberns@emory.edu or ariely@mit.edu

Abstract text (please fill no more than this page)

Humans tend to habituate to absolute levels of many types of stimuli, including wealth. Such adaptation can lead to a continuous pursuit of goals with lower than expected satisfaction – a phenomenon that has been termed the hedonic treadmill. Such adaptation implies that the value of objects will be dependent both on the average level of reward and the value of alternative outcomes (counterfactuals). Although well-documented for financial outcomes, the degree to which individuals adapt to non-financial rewards continues to be debated. To measure the source of these adaptations in the brain, we used fMRI to study the brain's response to visual reward and punishment in the form of pictures. Specifically, we hypothesized that "neutral" pictures can acquire value that depends on the context in which they are presented and that this value will be reflected in changes in activity in brain reward circuits.

FMRI and SCR data were collected (N=23) during the administration of selected pictures from the International Affective Picture System (IAPS). Pictures were presented in four blocks, each containing 12 emotional and 24 neutral pictures in randomized order. Although the valenced stimuli constituted the minority of pictures, they were used to establish an emotional tone for each block (either positive or negative). The level of this tone was then measured by the response to the neutral stimuli within these blocks. Following the presentation of each picture, participants rated how long they would like to see the picture if they were going to see them again. Outside of the scanner, all the pictures were rated by participants according to valence, arousal, and appeal.

The ratings of the emotional pictures were consistent with normative data, and there was no significant difference in arousal between positive and negative pictures. However, there was a trend toward significance on the neutral images, with neutral images in a positive context rated slightly higher in valence than neutral images in a negative context ($p=.06$). These results point to an assimilation, rather than contrast, in the processing of relative emotional inputs – suggesting that adaptation does not operate on such stimuli. Corresponding to these ratings, we observed significant differences in caudate activation associated with the processing of these neutral pictures within positive or negative emotional contexts, and these changes correlated with the subjective ratings of valence ($r2=0.41$). In summary, "neutral" stimuli may acquire value that depends on the context in which they are presented, but the context seems to operate via a generalized affect activation rather than via a contrast to adjacent stimuli.

Title: **Neurons in Orbitofrontal Cortex Process Economic Value in Abstract**

Authors: Camillo Padoa-Schioppa and John A. Assad

Institution: Department of Neurobiology, Harvard Medical School

Address: 200 Longwood Avenue, Boston, MA 02115

Email: camillo@hms.harvard.edu

Abstract text (please fill no more than this page)

Consider a monkey offered to choose between one raisin and one piece of apple. What mental operations underlie his choice? One simple hypothesis is that the monkey assigns values to the two foods and then decides consequently. This hypothesis predicts there be a neuronal population processing the value of the foods. "Value" is known to modulate the activity of neurons in a variety of sensory and motor areas. For example, neurons in parietal area LIP activate when a stimulus is placed in a particular location of the visual field; their responses are enhanced when the stimulus is associated with higher value. Analogous phenomena have been observed in several premotor areas. However, we argue that a value signal used for choice between foods (and more generally, between goods) should not depend on sensorimotor contingencies. In our example, the mental operations of choice should not be radically different if the raisin is presented on the right and the apple on the left, or vice versa. Likewise, the mental operations of choice should not depend on whether the monkey reaches his preferred food with the left hand or with the right hand. Here we show that neurons in orbitofrontal cortex (area 13) process value in abstract, independently of the sensory stimulus and the motor response.

In our experiments, monkeys choose between two types of juice offered in variable amounts. Trials begin with monkeys fixating the center of a monitor. Squares of different color and number displayed on opposite sides of the fixation point represent the offered juice types and amounts (left/right sides vary pseudo-randomly). After a delay, monkeys indicate their choice with an eye movement. The choice pattern provides a measure of the relative value of the two juices. We recorded and analyzed the responses of 375 neurons. Their activity almost never depends on the left/right position of the squares or on left/right side of choice. In contrast, the activity of 53% cells depends on the offer type. Three classes of responses are observed most frequently: "juice-value" (most prevalent shortly after the offer), reflecting the value of one of the two juices; "chosen value" (prevalent from the delay throughout juice delivery), reflecting the chosen value (the income) independent of juice type and amount; and "taste" (most prevalent before and after juice delivery), reflecting the chosen juice type independent of the amount. Notably, this matches well the mental processes monkeys presumably engage in during the trial.
In conclusion, neurons in orbitofrontal cortex seem a good candidate substrate for the neuronal processing of value assignment underlying economic choice.

Title: **Subjective Scaling of Neuronal Activity in Macaque Parietal and Cingulate Cortex**

Authors: Michael L. Platt, Allison N. McCoy, and Robert O. Deaner

Institution: Duke University Medical Center

Address: Dept. Neurobiology, 431 Bryan Research Bldg., Box 3209, Duke University, Durham, NC, 27710

Email: Platt@neuro.duke.edu

Abstract text (please fill no more than this page)
Decision-making models in economics, psychology, and behavioral ecology propose that organisms choose amongst options based on expected payoffs. Recent neurophysiological studies suggest that neurons in several brain areas linking visual perception with orienting track fluid reward value associated with visual targets. Here we show that neurons in cingulate and parietal cortex track subjective orienting biases for targets associated with uncertain rewards and the opportunity to view preferred social images, respectively, even when target fluid value is held constant. These data suggest that orienting decisions are made by scaling neuronal responses to targets by their subjective utility. Future studies focus on uncovering the sources of these biases, as well as how internal states, such as hunger or thirst, as well as social context, modulate psychological thresholds for scaling utility.

Poster Session I

Xu Cui, Chess Stetson, David M. Eagleman, P. Read Montague	Value of temporal uncertainty
Ming Hsu, Meghana Bhatt, Ralph Adolphs, Daniel Tranel, and Colin Camerer	Ambiguity aversion in the brain: Evidence from neuroimaging and lesion patients
M. Deppe, W. Schwindt, J. Kraemer, H. Kugel, H. Plassmann, P. Kenning	Evidence for a neural correlate of framing effects during credibility judgments
W. Schwindt, M. Deppe, H. Kugel, H. Plassmann, P. Kenning	An investigation of gender specific neural correlates of brand preference
Lis Nielsen, Brian Knutson, Gregory Larkin, Laura L. Carstensen	Affect dynamics: Tracking trajectories through affective space
H. Plassmann, P. Kenning, W. Schwindt, H. Kugel, M. Deppe	The role of the medial prefrontal cortex in risk modulated processing of implicit information during economic decision-making
M. Deppe, W. Schwindt, H. Kugel, H. Plassmann, P. Kenning	The role of the medial prefrontal cortex in preference processing during economic decision-making
Antonio Rangel, Carrie Armel	Visual attention and the construction of preferences in simple choice
Arthur Robson and Hillard Kaplan	The evolution of human life expectancy and intelligence in hunter-gatherer economies
Elke U. Weber and Hannah Bayer	Neural correlates of risk perception and risky decision making
Dongni Yang, Raika Pancaroglu, Justin Schwind, Lindsay Schwind, Nathan Apple, P. Read Montague	Neural correlates of taking perspectives during action and visualization
Paul Zak	Is it irrational to trust another person in a one-shot game? Neuroeconomic evidence

Title: **Value of Temporal Uncertainty**

Authors: Xu Cui[1], Chess Stetson[4], David M. Eagleman[4,5], P. Read Montague[2,3]

Institution: [1]Program in Structural and Computational Biology and Molecular Biophysics, [2]Department of Neuroscience, [3]Menninger Department of Psychiatry and Behavioral Science, Baylor College of Medicine, 1 Baylor Plaza, Houston, TX 77030, USA, [4]Department of Neurobiology and Anatomy, University of Texas Medical School, 6431 Fannin St, Suite 7046, Houston, TX 77030, USA, [5] Department of Biomedical Engineering, Department of Psychology, University of Texas at Austin, Austin, TX, USA

Address: Human Neuroimaging Lab, S104
Baylor College of Medicine
1 Baylor Plaza
Houston, TX 77030

Email: rmontague@hnl.bcm.tmc.edu

Abstract text (please fill no more than this page)
Value of a reward/punishment depends on whether it is delivered at the expected time or at a random time. For example, we strongly prefer an expected pain to an unexpected one. Here we studied how the temporal uncertainty influences human preference on monetary reward. Each participant completed 50 trials. In each trial he or she freely chose the red or yellow cue and then a dollar was delivered with probability and delay associated with the color. The delay is fixed for one color and randomized, with the same mean as the fixed delay, for the other color. The participants were not told the difference between the red and yellow trials. Color association is randomized across participants. We use alpha, the fraction that the participants chose the variant-delay trials, as the indicator of their preference.

We found that the participants prefered fixed-delay trials (alpha=0.45, p-value=0.003) in the block where the mean delay is 6s and red/yellow trials are equally rewarding. Increasing the reward probability of the variant-delay trial by 1/6, or decreasing the reward probability of the fixed-delay trial by 1/6, changes the preference to the variant-delay trials (alpha = 0.58, p-value < 0.0001). The participants, however, prefered the variant-delay trials where mean delay is 12s and red/yellow trials are equally rewarding.This suggests that there might exist different neural mechanisms for short and long delay.

Title: **Ambiguity Aversion in the Brain: Evidence from Neuroimaging and Lesion Patients**

Authors: Ming Hsu, Meghana Bhatt, Ralph Adolphs, Daniel Tranel, and Colin Camerer

Institution: California Institute of Technology
Iowa School of Medicine

Address: M-C 228-77
Pasadena, CA 91125

Email: camerer@hss.caltech.edu

Abstract text (please fill no more than this page)
Uncertainty about the outcome of a decision varies from risky (knowing a lot about the probability of an outcome) to ambiguous (when there is important missing information about an outcomes probability). fMRI shows two interacting systems for uncertain decision which are differentially active in risky and ambiguous choices:
(1) A general uncertainty system, involving the amygdala, and frontoinsular lateral orbitofrontal cortex (OFC), responds rapidly and is activated more strongly under ambiguity; and (2) a reward anticipation system in the striatum is activated more strongly when outcomes are risky. In behavioral experiments, patients with lesions overlapping the uncertainty-system regions are insensitive to the difference between risk and ambiguity. These fMRI and lesion-patient data establish a clear distinction between risky and ambiguous decision making in humans.

Title: **Evidence for a neural correlate of framing effects during credibility judgments**

Authors: M. Deppe[1], W. Schwindt[2], J. Kraemer[1], H. Kugel[2], H. Plassmann[3], P. Kenning[3]

Institution: [1] Department of Neurology, [2] Department of Clinical Radiology, [3] Department of General Management, University of Muenster

Address:
Am Stadtgraben 13-15
48143 Muenster
Germany

Email: peter.kenning@wiwi.uni-muenster.de

Abstract text (please fill no more than this page)
Background:
Neural processes within the medial prefrontal cortex play a crucial role in assessing and integrating emotional and other implicit information during decision-making. Phylogenetically, it was important for the individual to assess the relevance of all kinds of environmental stimuli in order to adapt behavior in a flexible manner. Consequently, we can in principle not exclude that environmental information covertly influences the evaluation of actually decision relevant facts ("framing effect").
Objective:
To test the hypothesis that the medial prefrontal cortex is involved into a framing effect we employed functional magnetic resonance imaging (fMRI) during a binary credibility judgment task.
Methods:
Twenty-one subjects were asked to judge 30 normalized news magazine headlines by forced answers as "True" or "False". To confound the judgments by formally irrelevant framing information we presented each of the headlines in four different news magazines characterized by varying credibility. For each subject the susceptibility to the judgment confounder (framing information) was assessed by magazine-specific modifications of the answers given.
Results:
We could show that individual activity changes of the ventromedial prefrontal cortex during the judgments correlate with the degree of an individual's susceptibility to the framing information.
Conclusion:
We found (i) a neural correlate of a framing effect as postulated by behavioral decision theorists that (ii) reflects interindividual differences in the degree of the susceptibility to framing information.

Title: **An investigation of gender specific neural correlates of brand preference**

Authors: W. Schwindt[2], M. Deppe[1], H. Kugel[2], H. Plassmann[3], P. Kenning[3]

Institution: [1] Department of Neurology, [2] Department of Clinical Radiology, [3] Department of General Management, University of Muenster

Address:
Am Stadtgraben 13-15
48143 Muenster
Germany

Email: peter.kenning@wiwi.uni-muenster.de

Abstract text (please fill no more than this page)
In current consumer behavior textbooks and articles statements about gender specific differences in product information processing and decision-making mechanisms can be found. These assumptions can not be supported by any neuroscientific study. In spite of the assumed differences, the brain mechanisms underlying economic decision-making in favor of a special product may be similar for both genders.
Earlier results of our study showed that significant brain activation differences during decision making between sensorily similar fast moving consumer goods occurred only in the presence of the subject's favorite brand. We found decreased activations in areas associated with working memory and rational decision making, while activations were increased in areas responsible for integrating emotions into the decision making process, i.e. the decision making was modulated by implicit brand information.
We reanalyzed our data to test, whether there are gender dependent activation differences during economic decision making.
Methods:
Two separate cohorts of twelve male (median age 23) and ten female (median age 22) subjects had to decide between pairs of sensorily similar consumer goods, which were 15 coffee brands for the female group and 20 beer brands for the male group. One of the respective market leaders was chosen as a target brand T, the others where classified as diverse brands D. The stimulation during fMRI at 3.0 T was designed as a pseudo-randomized block design and consisted of 10 alternating blocks with 80 and 20 % TD decisions, respectively. We performed a random effects analysis for all male and female subjects with the gender as the grouping factor, i.e. we generated the contrasts (male – female and female – male).
Results:
The results of the gender dependent differences are as follows. We found no significant differnce in processing brand information during choice tasks ($p<0.05$, corrected for multiple comparisons, cluster size 0 voxel)
Summary and Conclusion:
Of course the virtual absence of statistically significant gender dependent activation differences does not necessarily imply equivalence. Still, our results indicate that any such potential differences are magnitudes smaller than the previously described effect, which is elicited solely by the presence of the subject's favorite brand and produced highly congruent activation patterns between the male and female study group.
In spite of the differences in the what and how of buying, whether being shaped by our chromosomes or by society, our results suggest that the basic brain mechanisms underlying buying decisions are at least very similar between the sexes.

Title: **Affect Dynamics: Tracking Trajectories through Affective Space**

Authors: Lis Nielsen[1], Brian Knutson[2], Gregory Larkin[2], Laura L. Carstensen[2]

Institution: [1] National Institute on Aging, [2] Stanford University

Address: National Institute on Aging, Behavioral and Social Research Program, 7201 Wisconsin Ave., #533, Bethesda, MD 20892

Email: nielsenli@nia.nih.gov

Abstract text (please fill no more than this page)
Affective experience, as defined by independent dimensions of valence and arousal, can change rapidly. Yet empirical measures rarely capture the dynamics of subjective experience on a second-to-second timescale. We investigated whether "affect dynamics" could be reliably probed in real time during a task in which participants anticipated and received monetary incentives. We predicted that subjective experience would show systematic but distinct changes during incentive anticipation versus outcomes. In Study 1, the use of affect probes during the experimental task supported both hypotheses, suggesting that anticipation of incentives altered both valence and arousal, whereas incentive outcomes primarily changed valence. In Study 2, inexperienced participants could not accurately predict online changes in arousal, suggesting that results of Study 1 were not simply due to demand characteristics. These results suggest that affect dynamics can change in ways that participants do not predict and demonstrate the feasibility of probing affect dynamics in real time.

Title: **The role of the medial prefrontal cortex in risk modulated processing of implicit information during economic decision-making**

Authors: H. Plassmann[3], P. Kenning[3], W. Schwindt[2], H. Kugel[2], M. Deppe[1]

Institution: [1] Department of Neurology, [2] Department of Clinical Radiology, [3] Department of General Management, University of Muenster

Address: Am Stadtgraben 13-15
48143 Muenster
Germany

Email: hilke.plassmann@wiwi.uni-muenster.de

Abstract text (please fill no more than this page)
In a companion paper (Deppe et al. 2005) we could show, that the medial part of the prefrontal cortex plays a crucial role during a simplified economic choice task by integrating emotionalized information into the decision. Here we targeted the question whether risk information can modulate the activity within this region during economic choice tasks based on a natural sample of real-life decisions.
Methods:
During high-field fMRI at 3.0 T four male and six female healthy students performed brand choice tasks. The stimulation paradigm was designed to assess differences in brain activity between risk modulated decisions in presence or absence of the subject's favorite brand. We employed a two-factorial design (factor 1: brand, levels = favorite (F), diverse (D); factor 2: risk, levels = high (H), low (L)) resulting in four types of decisions. As stimulation material we used 16 travel business brands and a risky versus a less risky travel destination. As statistical analysis we employed a two level random effects model to assess the interaction effects between the presence of the favorite brand during high-risk versus low-risk decisions (FH-FL) and the absence of the favorite during high-risk versus low-risk decisions (DH-DL).
Results and Discussion:
We found highly significant interactions between both, brand information and risk information processing ($p<0.0001$, corrected, min cluster size 10 voxels).
During the interaction of risk modulated processing of brand information in presence and absence of the favorite brand (FH-FL vs. DH-DL-decisions) we found increased activations in the left and right ventromedial prefrontal cortex (BA 10), the left anterior cingulate (BA 32), and the right precuneus in the occipital/parietal lobe, (BA 31). The most prominent effects were found in the medial prefrontal cortex (MPFC).
The MPFC is involved in integrating emotions in decision-making, emotion-related learning, and decision-making under risk (Bechara 2004). However, the interaction between emotion and risk has only been analyzed in a few studies. The information processing related to the favorite brand leads to more increased activations in the MPFC during choices under high-risk information. This activation occurred congruently in regions which are involved in reward processing described by the current literature.
Conclusion:
In a more complex economic choice task integrating risk as a second factor the "favorite brand effect" (Deppe et al. 2005) is more salient, when the subjects face risky decisions. Thus, during risky preference decisions in real-life situations, the processing of information related to our favorite-brand seems to be specifically stronger influenced by emotional involvements of rewards than those of "non favorite brands".

Title: **The role of the medial prefrontal cortex in preference processing during economic decision-making**

Authors: M. Deppe[1], W. Schwindt[2], H. Kugel[2], H. Plassmann[3], P. Kenning[3]

Institution: [1] Department of Neurology, [2] Department of Clinical Radiology, [3] Department of General Management, University of Muenster

Address:
Am Stadtgraben 13-15
48143 Muenster
Germany

Email: hilke.plassmann@wiwi.uni-muenster.de

Abstract text (please fill no more than this page)
Why do people frequently favor consequently one particular brand of commodity goods (e.g. Coca Cola) above others (e.g. Pepsi)? It is well known that buyers of "fizzy brown sugar water" usually can not differentiate different brands of this product type by their taste and are usually not able to recognize their favorite brand if they participate on a blinded study. Here we investigated whether it is possible to find a neural correlate by neuroimaging which could provide new insights how brands influence buying decisions.
Methods:
During high-field fMRI at 3.0 T twelve male and ten female healthy students performed buying decisions. The stimulation paradigm was designed to assess differences in brain activity between decisions in presence or absence of a specific target brand (T). We employed two buying decisions types in a pseudo randomized order (type 1: a target brand versus various diverse (D) other brands (= TD decisions), type 2: diverse versus other diverse brands (= DD decisions)). As products we used coffee and beer. Three types of statistical analysis (SPM) were employed: (i) a one level fixed effects design to estimate the volunteers' individual effects (contrasts: TD-DD, DD-TD), (ii) a linear regression concerning the target brand ranking order relative to the diverse brands and (iii) a two level random effects model to assess group differences.
Results:
Only when the target brand was the subjects' favorite brand (this was the case for 3 male and 5 female subjects, verified by behavioral data), we found significant differences between TD and DD decisions ($p<0,05$, corrected, min cluster size 20 voxels). During TD decisions we found reduced activations in the dorsolateral prefrontal, the posterior parietal and occipital cortices and the left premotor area (Brodmann areas (BA) 9, 46, 7/19 and 6) in contrast to DD decisions in the 8 subjects. Simultaneously activity was increased in inferior precuneus and posterior cingulate (BA 7), right superior frontal gyrus (BA10), right supramarginal gyrus (BA 40), and pronounced in the ventromedial prefrontal cortex (BA 10). The random effects analysis provided evidence for significant differences in cortical processing between the subjects which ranked the target brand first and the subjects which rated the target second or lower. The most prominent effects were found in the medial prefrontal cortex . No linear relation was found between ranking order and brain activation.
Discussion:
The orbitofrontal and medial prefrontal cortex are implicated in emotion and emotion-related learning and decision-making. Other groups (e.g. O'Doherty et al.) found distinct areas of the prefrontal cortex which showed a correlation between the magnitude of the brain activation and the magnitude of rewards and punishments received. Our prefrontal activation modulations induced by the "favorite brand" occurred congruently in the regions described by the latter study.

Title: **Visual attention and the Construction of Preferences in Simple Choice**

Authors: Antonio Rangel, Carrie Armel

Institution: Stanford University, Department of Economics

Address: Department of Economics, Stanford University, Stanford, CA 94305

Email: rangel@stanford.edu

Abstract text (please fill no more than this page)
In order to make choices the brain needs to compute a value for the different alternatives under consideration which is use to evaluate their relative "desirability". We refer to this variable as a hedonic forecast (HF). We study how the brain constructs these HFs in real-time in simple choice situations between items that are familiar from previous consumption/exposure and in which self-control conflicts are not an issue.
We propose a mathematical model of how the brain make these choices based on the operations and properties of 3 brain processes: (P1) A process that guides visual attention, (P2) A process that constructs the HFs, and (P3) a process that determines when and what choice is made. The model describes the dynamics of these three processes in real-time and generates novel testable predictions for the following types of variables: eye movements, RTs, choices, intransitivies in choice or mistakes, and other behavioral variables. The model is a hybrid of methods in computational neuroscience and economic theory.
We present results from a series of experiments that use behavioral and eye tracking techniques to (1) test the main assumptions and predictions of the model and (2) characterize some of the key parameters of the model.

Title**: The evolution of human life expectancy and intelligence in hunter-gatherer economies**

Authors: Arthur Robson* and Hillard Kaplan

Institution: Simon Fraser University

Address: Department of Economics
Simon Fraser University
8888 University Drive
Burnaby, BC
Canada V5A 1S6

Email: robson@sfu.ca

Abstract text (please fill no more than this page)

THE EVOLUTION OF HUMAN LIFE EXPECTANCY AND INTELLIGENCE IN HUNTER-GATHERER ECONOMIES

The economics of hunting and gathering may well have driven the biological evolution of human characteristics, since hunter-gatherer societies prevailed for the two million years of human history. These societies feature huge intergenerational resource flows, for example, suggesting that these resource flows should replace fertility as the key demographic considerations. This suggests an alternative view of the relationship between economics and biology. Rather than viewing human biological characteristics as effectively exogenous determinants of economic phenomena, we consider how the economics of hunter-gatherer societies shaped economically relevant human biological characteristics by means of natural selection.

In particular, in considering why intelligence and life expectancy are simultaneously exaggerated in humans, it is relevant that these variables are robustly associated across living species, and across primates, in particular. For example, a human brain is at least three times bigger than that of a chimpanzee and humans live about two times longer. In addition, intelligence and longevity seem to have coevolved in human evolutionary history.

To explain this close connection between intelligence and life expectancy, this paper models the brain as a form of capital. It is then theoretically expected that life expectancy and brain size would increase simultaneously. The brain here is considered as a direct form of bodily investment, but also crucially as facilitating further indirect investment by means of learning-by-doing. The paper then derives the dynamic paths of investment and of expenditure to reduce mortality, so to better reap the returns on such investment.

Title: **Neural correlates of risk perception and risky decision making**

Authors: Elke U. Weber & Hannah Bayer

Institution: Columbia University

Address: 3022 Broadway, 716 Uris, New York, NY 10027

Email: euw2@columbia.edu

Abstract text (please fill no more than this page)
While there are currently several powerful normative and descriptive accounts of behavioral choice (e.g., EU theory, prospect theory, risk--return models), the processes by which choices are made remain an open question. 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 options which differed in expected value, variance (the index of riskiness used widely in economics, e.g. risky options pricing models like CAPM) or in the coefficient of variation (defined as the standard deviation divided by expected value, a relative measure of risk per unit of return, consistent with Weber's law). Subjects were asked how much they would be willing to pay to have a chance to own (and play) a risky option. By using options which spanned a wide range of risk levels, each individual's risk preference function was determined. 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.

Title: **Neural correlates of taking perspectives during action visualization**

Authors: Dongni Yang, Raika Pancaroglu, Justin Schwind, Lindsay Schwind, Nathan Apple, P. Read Montague *

Institution: *Department of Neuroscience and Menninger Department of Psychiatry and Behavioral Sciences, Baylor College of Medicine, 1 Baylor Plaza,
Houston, Texas 77030, USA

Address: Human Neuroimaging Laboratory, S104
Baylor College of Medicine
1 Baylor Plaza,
Houston, Texas 77030, USA

Email: dyang@hnl.bcm.tmc.edu

Abstract text (please fill no more than this page)
Ability to visualize or imagine one's own actions and other's actions is important for action evaluation and decision making. Depending on the subjects (self/other person) visualized and the perspectives taken, different neural processes may be involved in the visualization process. To determine the neural correlates of taking perspectives and visualizing actions, we designed a task in which subjects visualized/viewed oneself exercising from a 1st person perspective or from a 3rd person perspective. Subjects were also asked to visualize/view someone else exercising from a 3rd person perspective. 13 subjects were recruited to be trained on lifting weight and running stairs. Professional athletes were also recruited. BOLD signals were measured using fMRI while they were visualizing/viewing. Data was analyzed using SPM2.

Areas including SMA, inferior frontal gyrus and left angular gyrus are activated in all conditions during visualization. SMA activity is highest when visualizing from a 1st person perspective. Cuneus/precuneus activity is higher during visualizing from a 3rd person perspective compared to from a 1st person perspective. Putamen is more significantly activated during visualization of oneself from a 1st person perspective than from a 3rd person perspective. Our results indicate that cuneus/precuneus, putamen and SMA are differentially activated during visualization of physical exercise from different perspectives.

Acknowledgement

This study was funded by The Kane Foundation. We thank Jian Li and Xu Cui for helpful comments.

Title: **Is it irrational to trust another person in a one-shot game? Neuroeconomic evidence**

Authors: Paul J. Zak

Institution: Claremont Graduate University

Address: Center for Neuroeconomics Studies, 160 E. 10th St., Claremont, CA 91711-6165

Email: paul@pauljzak.com

Abstract text (please fill no more than this page)
The subgame perfect (SGP) Nash equilibrium of the Berg et al. "trust game" predicts no trust and no trustworthiness. In a recent one-shot game experiment (N=212), those playing the SGP Nash strategy earned the $10 show-up payment, while on average, decision-maker 1s (DM1s) earned $14 and decision-maker 2s (DM2s) earned $17, suggesting that a "rational" strategy is to be trusting (and perhaps, trustworthy). This talk will review a number of recent neuroeconomic studies using the trust game that show that trust and trustworthiness are associated with neural activation in areas in the brain associated with cognition, as well as brain regions that are more primitive. This suggests that trusting behaviors may utilize two or more primary neural pathways, both "rational" and "irrational."

Saturday, September 17, 2005

Slide session, chaired by Elke Weber

Games

9:00 - 9:30 am	Ernst Fehr	Oxytocin increases trust in humans	University of Zurich
9:30 - 10:00 am	Ben Seymour	The perceived fairness of others modulates empathic brain responses to their pain: neural evidence for 'Schadenfreude' in men but not women	University College London
10:00 - 10:30 am	Daniel Houser	Emotion expression in human punishment behavior	George Mason University
10:30 - 11:00 am	Coffee Break		
11:00 - 11:30 am	Colin Camerer	Eyetracking and pupil dilation in deception in games	Caltech
11:30 am - 12:00 pm	Xiao-Jing Wang	Exploring neural mechanisms of a mixed-strategy: a microcircuit model of random decision dynamics in competitive games	Brandeis University
12:00 - 12:30 pm	Mauricio Delgado	The neural circuitry of winning and losing in experimental auctions	New York University
12:30 - 1:30 pm	Lunch		
1:30 - 2:00 pm	Aldo Rustichini	Eye to eye communication	University of Minnesota
2:00 – 2:30 pm	Discussion		

Title: **Oxytocin increases trust in humans**

Authors: Michael Kosfel, Markus Heinrichs, Paul Zak, Urs Fischbacher, Ernst Fehr

Institution: Institute for Empirical Research in Economics, University of Zurich

Address: Blumlisalpstrasse 10, CH - 8006 Zurich

Email: efehr@iew.unizh.ch

Abstract text (please fill no more than this page)
Trust pervades human societies. Trust is indispensable in friendship, love, families, and organizations and further plays a key role in economic exchange and politics. In the absence of trust among trading partners, market transactions break down. In the absence of trust in a country's institutions and leaders, political legitimacy breaks down. Much recent evidence indicates that trust contributes to economic, political, and social success. Little is known, however, about the biological basis of trust among humans. Here we show that the intranasal administration of oxytocin, a neuropeptide that plays a key role in social attachment and affiliation in non-human mammals and that has been shown to cross the blood-brain barrier, causes a substantial increase in trust among humans, thereby greatly increasing the benefits from social interactions. We also show that the effect of oxytocin on trust is not due to a general increase in the acceptance of risks. Rather, oxytocin specifically affects the individual's willingness to accept social risks arising in interpersonal interactions. These results concur with animal research suggesting an essential role of oxytocin as a biological basis of prosocial approach behaviour.

Title: **The Perceived Fairness of Others Modulates Empathic Brain Responses to their Pain: Neural Evidence for 'Schadenfreude' in Men but not Women**

Authors: Tania Singer, Ben Seymour, John O'Doherty, Klaas Stepahn, Raymond J. Dolan and Chris D. Frith

Institution: University College London

Address: Wellcome Department of Imaging Neuroscience, UCL
12 Queen Square, London, UK

Email: t.singer@fil.ion.ucl.ac.uk

Abstract text (please fill no more than this page)
Using functional imaging, we assessed whether empathic brain responses to the pain of others are modulated as a function of perceived fairness of others. Specifically, we engaged volunteers and confederates in an economic game, a repeated version of a sequential Prisoners Dilemma Game. Confederates either played fairly or unfairly. In a second step, we then compared brain activity while the naïve subjects either experienced painful stimuli to self, or perceived the fair and unfair player receiving painful stimulation. Women and men show empathy-related activation in fronto-insular cortex (FI) and anterior cingulate cortex (ACC) when they see an unfamiliar but fair person in pain. In contrast, men but not women showed a lack of pain-related responses when perceiving an unfair person receiving pain. Furthermore, men but not women, showed increased activation in reward-related areas such as nucleus accumbens and orbitofrontal cortex in this same context. This activity correlated with their expressed desire for revenge. We conclude that, at least in men, empathic responses are modulated as a function of the personal valuation of other people's previous behavior, and illustrate the neural basis of 'Schadenfreude' - the satisfaction on seeing someone we dislike suffer.

Title: **Emotion expression in human punishment behavior**

Authors: Erte Xiao and Daniel Houser

Institution: George Mason University

Address: 4400 University Blvd. MSN 1B2 Fairfax, VA 22015

Email: dhouser@gmu.edu

Abstract text (please fill no more than this page)
Evolutionary theory reveals that punishment is effective in promoting cooperation and maintaining social norms. Although it is accepted that emotions are connected to punishment decisions, there remains substantial debate over why humans use costly punishment. Here we show experimentally that constraints on emotion expression can increase the use of costly punishment. We report data from Ultimatum Games, where a proposer offers a division of a sum of money and a responder decides whether to accept the split, or reject and leave both players with nothing. Compared to the treatment where expressing emotions directly to proposers is prohibited, rejection of unfair offers is significantly less frequent when responders can convey their feelings to the proposer concurrently with their decisions. These data support the view that costly punishment might itself be used to express negative emotions, and suggest that future studies will benefit by recognizing that human demand for emotion expression can have significant behavioral consequences in social environments including families, courts, companies and markets.

Title: **Eyetracking and pupil dilation in deception in games**

Authors: Colin Camerer, Moran Surf, Joseph Wang

Institution: Caltech

Address: Div HSS 228-77 Caltech Pasadena CA 91125 USA

Email: camerer@hss.caltech.edu

Abstract text (please fill no more than this page)
In game theory, deception about a state of the world or intended future play is often part of equilibrium play—that is, it is optimal for a message-sender to deceive given how message-receivers react. Furthermore, in equilibrium a receiver expects to be deceived. We use eyetracking and pupil dilation measurement (PDR) to study deception in a sender-receiver game of biased information transmission (see Cai and Wang, GEB in press). The sender observes a true state of the world (a number N) and conveys a message to the receiver, who then picks a number. The sender wants the receiver to pick N+b, where b is a bias term (possibly b=0) and the receiver wants to pick the true number N. The game models phenomena like security analyst forecasting, in which analysts have an incentive to exaggerate the quality of a firm, but investors know analysts may exaggerate. Eyetracking enables us to identify algorithmic strategies (including optimal deception, and truth-telling) and construct a model that uses eye movements and PDR to try to detect deception.

Title: **Exploring neural mechanisms of a mixed-strategy:**
A microcircuit model of random decision dynamics in competitive games

Authors: Alireza Soltani and Xiao-Jing Wang

Institution: Brandeis University

Address: Center for Complex Systems MS 013, Brandeis University, 415 South Street, Waltham 02454

Email: xjwang@brandeis.edu

Abstract text (please fill no more than this page)
There is recently a surge of neurobiological studies aimed at understanding the neural basis of dynamic decision making processes. In one experiment by Sugrue et al, the monkey is trained to choose between t two visual targets, which are rewarded with different probabilities. It was found that the monkey's choice behavior follows the `matching law', namely the ratio of probabilities for choosing the two targets matches that of harvested rewards. In another experiment, Barraclough et al trained the monkey to play the game of matching pennies by selecting between two visual targets. Both experiments have been computer simulated by reinforcement learning models. These models, however, do not seem to address a fundamental difference between the two experiments. Namely, in the matching task the monkey can repeatedly choose the target with higher reward probability but also sample the target with lower reward probability less frequently, whereas in the game of matching pennies the monkey must not exhibit any predictable pattern of choice selection. However, that the optimal behavior is to play randomly does not mean that the monkey should ignore the opponent's choice behavior or occurrence of reward on a specific target. In fact, it was shown that monkeys are able to learn a specific strategy called win-stay-lose-switch very gradually and to increase the use of this strategy when it is successful.

Two important questions arise from these observations: how does the monkey play randomly by observing feedbacks, and how can it develop a strategy? We investigated these questions using a biophysically plausible decision-making network. Results of our model, based on reward-dependent learning alone, show that in order to account for the behavior observed in the matching pennies experiment, one must assume extremely slow learning rate in a hard-wired stochastic decision network. This assumption is somewhat implausible biologically, and does not shed true insights into local (trial-by-trial) decision dynamics that ultimately lead to random choice behavior. Motivated by recorded neural activities from the prefrontal cortex, we propose here a new model for generating random choice behavior with two modules. One module is a decision making network that computes monkey's choice (left or right targets), whereas the other module encodes and integrates across trials the computer opponent's choices. Both modules are endowed with reward-dependent synaptic plasticity, and reciprocal connections between them. We show that under certain conditions these interacting modules are able to generate random behavior in a dynamic way. The same model can be used to learn a specific strategy. Furthermore, we show additional mechanisms, such as meta-learning (Schweighofer et al), enable our model to adapt to different strategies when the opponent's strategy has changed, for instance when the computer opponent switches from algorithm 1 to algorithm 2 in the experiment of Barraclough et al.

Barraclough DJ, Conroy ML, Lee D (2004) Nature Neuroscience 7: 404-410
Schweighofer N, Doya K (2003) Neural Network16(1): 5-9
Sugrue LP, Corrado GS, Newsome WT (2004) Science 304: 1782-7

Title: **The neural circuitry of winning and losing in experimental auctions**

Authors: Mauricio Delgado, Andrew Schotter, Daniel Schwarz, Elizabeth Phelps

Institution: New York University

Address: 6 Washington Place, Room 873 - Dept. of Psychology, New York, NY 10003

Email: m.delgado@nyu.edu

Abstract text (please fill no more than this page)

It has often been noted by economists that in auction experiments subjects tend to bid higher than the bids prescribed by the risk-neutral Nash equilibrium. Two competing explanations for this phenomenon exist. In one, the "overbidding" is ascribed to risk aversion on the part of the subjects, while in the other it is ascribed to the "joy of winning". These two hypotheses have been tested against each using behavioral data generated by the auctions. The standard result is that no significant effect of the "joy of winning" is typically found. The following study investigated the utility of winning by tracking the hemodynamic response to winning and losing in reward-related areas while modulating variables such as competition (another person vs. computer) and type of incentive (money vs. points). Participants played an "auction game" where they bid against an experimental cohort, a confederate, to buy one unit of a fictitious good. Participants also played a "lottery game" with similar rules as the auction, except against a computer, rather than a human opponent. Behavioral results based on subjective ratings offered little support for the "joy of winning" hypothesis, consistent with previous economic studies. Preliminary imaging results in reward-related areas also failed to support such a hypothesis. However, the results suggested that the fear of losing may play a critical role in auction behavior.

Title: **Eye to Eye Communication**

Authors: Lungu, Rustichini, Vostroknutov

Institution: Department of Economics, University of Minnesota

Address: 1035 Heller Hall, 271, 19th Avenue South, Minneapolis, MN, 55455

Email: arust@econ.umn.edu

Abstract text (please fill no more than this page)
Empathy is the ability of the observer to reproduce the internal states of others, either when observing an external event or the display of a reaction, motor or affective. We test the hypothesis that empathy is used as an information extracting device: the reproduction of the neural activity of the observed subject provides a signal on the information available to the observed subject. An implication of the theory is that a subject has very little to know on his own internal states, so brain activity related to empathy should be smaller than it is when a different subject is involved.

We test this hypothesis using the simplest form of interpersonal communication: the exchange of gazes among human subjects, including the subject looking at himself. Five different conditions have been used. The key comparisons are between the brain activity of a subject when he is looking at a different person and when he is looking at his own eyes. In other conditions, subjects are looking at an observer who is not looking, or they are looked at as they are not looking.

A group of 29 subjects has been observed in an fMRI study. The results support the hypothesis of empathy as an information acquisition. The activation of the area BA 44 is strongest when two subjects exchange gazes, is weaker when a subject is not looking and the other is looking, still weaker when the subject is looking at himself.

The lowest activation occurs when the subject is looking at a fixed picture or when the opponent is not looking. In summary, activation of an area like BA44, which is mostly devoted to communication, is roughly proportional to the occurrence or to the potential for communication between the two subjects. Similar patterns are found for Anterior Insula and Cingulate.

Poster Session II

Heather L. Dean, Ernesto Soares, Allison N. McCoy, Arwen Long, and Michael L. Platt	Microstimulation in macaque posterior cingulated cortex biases target choice
Mauricio Delgado, Christa Labouliere, Elizabeth Phelps	Fear of losing money: Aversive conditioning with secondary reinforcers
Ann H. Harvey, Ronald E. Fisher, Jian Li, Xu Cui, P. Read Montague	Role of ventromedial prefrontal cortex in the evaluation of diverse rewards
Scott Huettel	Neural substrates for the resolution of uncertainty
Brooks King-Casas, Jian Li, Urs Fischbacher, Ernst Fehr, P Read Montague	Neural correlates of competition within an Ultimatum Game
Alison Adcock, Brian Knutson, John Gabrieli	Motivation modulates memory: Neurally linking affect and cognition
Ifat Levy, Jason Snell, Aldo Rustichini, and Paul W. Glimcher	Behavioral characteristics and neural correlates of decision-making under ambiguity
Jian Li, Michele York, P. Read Montague	Neural correlates o reinforcement learning in Parkinson's Disease
Terry Lohrenz, Kevin McCabe, P.Read Montague	An fMRI study of decision making in a trading simulation
Arwen Long, Allison N. McCoy, Sheila Roberts and Michael L. Platt	Effects of rapid tryptophan depletion on risk preferences in macaques
Kenway Louie and Paul W. Glimcher	Intertemporal choice behavior in monkeys: Interaction between delay to reward, subjective value, and area LIP
Kerstin Preuschoff, Peter Bossaerts and Steve Quartz	Human fMRI evidence for the neural correlates of Option Valuation Theory
Robb Rutledge, Brian Lau, and Paul W. Glimcher	Human matching behavior in a dynamic environment
Vasily Klucharev, Guillen Fernandez, and Ale Smidts	Why are celebrities effective: An fMRI study into episodic memory effects of presenter context
Veit Stuphorn, Vijay C. Kannan	Human discounting functions with non-monetary reward
Damon Tomlin, Brooks King-Casas, Cedric Anen, Steven R. Quartz, and P. Read Montague	Exchange task reveals differential neural responses across social context and gender
Naoshige Uchida and Zachary F. Mainen	The role of stimulus and reward history on updating decision making strategy in an odor mixture discrimination task
J. White, N. Apple, J. Shin, and P. R. Montague	Hyperscanning: A system for conducting synchronized multi-subject multi-institution neuroimaging experiments over the internet

Title: **Microstimulation in Macque Posterior Cingulate Cortex Biases Target Choice**

Authors: Heather L. Dean, Ernesto Soares, Allison N. McCoy, Arwen Long, and Michael L. Platt

Institution: Duke University Medical Center

Address: Dept. Neurobiology, 431 Bryan Research Bldg., Box 3209, Duke University, Durham, NC, 27710

Email: dean@neuro.duke.edu

Abstract text (please fill no more than this page)
Neurons in posterior cingulate cortex (CGp) signal both the expected value of orienting to visual targets and the motivational consequences of orienting to those targets (McCoy et al. 2003). These data suggest the hypothesis that CGp activation binds motivational information to locations in visual space. If so, then microstimulation during the delay period on target choice trials should bias monkeys to choose the contralateral target. Similarly, microstimulation delivered coincident with rewards delivered after contralateral target choices should enhance the subjective value of that target, thereby leading to a future choice bias for that target. To test this hypothesis, monkeys performed two blocks of target choice trials, one with microstimulation and one without. In each block, all choices were rewarded with the same volume of juice. We found that microstimulation in CGp during the delay period on choice trials biased choices towards the contralateral target, despite the fact that juice rewards were equivalent. Specifically, in 6 out of 9 stimulation experiments conducted thus far, 400 Hz microstimulation during the delay period in CGp was followed by a 15-30% increase in the frequency of choosing the contralateral target compared with blocks of trials with no stimulation. Stimulation during the delay period also decreased saccade latency on choice trials (ANOVA, $p < 0.05$). Stimulation at 50 Hz produced similar but weaker results. Stimulation coincident with juice rewards also produced a systematic change in target choice probabilities. In 6 such experiments, stimulation coincident with reward delivery on contralateral choices weakly (~10% on average) biased choices in that direction (n=6, t-test, $p < 0.002$). These results may represent a combination of stimulation-induced bias and a compensatory bias on trials with no stimulation. Artificial activation of CGp neurons thus appears to enhance the motivational salience of contralateral space, thereby biasing visual orienting.

Title: **Fear of losing money: Aversive conditioning with secondary reinforcers**

Authors: Mauricio Delgado, Christa Labouliere, Elizabeth Phelps

Institution: New York University

Address: 6 Washington Place, Room 873 - Dept. of Psychology, New York, NY 10003

Email: m.delgado@nyu.edu

Abstract text (please fill no more than this page)

Money is a powerful incentive. A secondary reinforcer, monetary incentives have been found to influence behavior and modulate areas of the brain involved in appetitive processing. It is unclear, however, if money can have similar influences in aversive processing. The goal of this study is to investigate the efficacy of money, a secondary reinforcer, in aversive learning, where primary reinforcers such as shock are normally used. We hypothesized that loss of money can serve as an aversive reinforcer and therefore modulate behavior and associated neural circuitry. During a two-part experiment, participants first played a gambling game involving blocks of trials that differed in incentive (monetary x non-monetary feedback), leading to a monetary gain of $36.00. During the second part of the experiment, participants were presented with a fear-conditioning paradigm, where loss of money ($2.00) served as the unconditioned stimulus (US) and was paired with one of two colored squares, the conditioned stimuli (CS+ and CS-, respectively). Skin conductance responses (SCRs) were acquired at the onset of each trial during the gambling game and for each CS presentation during the conditioning paradigm. Participants showed higher SCRs while playing the game when the incentive was monetary. More interestingly, higher SCRs were observed for CS+ compared to CS- trials, suggesting that a secondary reinforcer such as money can be an effective aversive US capable of influencing the physiological correlates of fear. In a subsequent follow-up experiment, the strength of money as a reinforcer in aversive learning experiments was tested by comparing secondary (i.e., loss of money) and primary (i.e., shock) reinforcers during the same and separate conditioning sessions. Both physiological and subjective measures suggested that loss of money can be as efficient as shock at driving conditioning, and that such efficacy is modulated by the presentation context.

Title: **Role of Ventromedial Prefrontal Cortex in the Evaluation of Diverse Rewards**

Authors: Ann H. Harvey[1], Ronald E. Fisher[2], Jian Li[1], Xu Cui[1], **P. Read Montague**[1]

Institution: [1]Human Neuroimaging Laboratory, Department of Neuroscience, Baylor College of Medicine
[2]Departments of Radiology and Neuroscience, Methodist Hospital, Baylor College of Medicine

Address: One Baylor Plaza, S104 Houston, TX 77030

Email: Read@bcm.tmc.edu

Abstract text (please fill no more than this page)
All nervous systems perform continuous economic evaluations of rewarding stimuli, both in terms of cost and potential payoff. Behavioral decisions require that widely diverse stimuli be directly compared with each other in terms of reward value; this in turn implies internal translation of the value of each stimulus into a common currency system (Montague and Berns, *Neuron* 36:265, 2002). The nature and anatomical location of this conversion and comparison process is not yet known, although evidence for a role of orbitofrontal-striatal and dopaminergic circuits exists. We performed fMRI scanning experiments on a total of 70 human subjects engaged in a variety of tasks. Some subjects passively viewed aesthetic stimuli (paintings) in the scanner and afterwards rated each painting for familiarity and liking. Some subjects were scanned while receiving squirts of culturally familiar beverages (Pepsi® and Coke®) and later expressed their preferences for the two drinks both in a questionnaire and during a blind taste test. Neural activity within a limited region of the ventromedial prefrontal cortex (VMPFC) correlated significantly with subjective preference for passively viewed paintings and behaviorally expressed preference for beverages. Thus, we find that activity in the VMPFC in humans is modulated by a variety of stimuli representing very different types of reward. We propose that this region may be involved in the comparative evaluation of diverse rewards.

Title: **Neural substrates for the resolution of uncertainty**

Authors: Scott A. Huettel

Institution: Duke University Medical Center

Address: 163 Bell Research Building
Duke University Medical Center, Box 3918
Durham, NC 27710

Email: scott.huettel@duke.edu

Abstract text (please fill no more than this page)
A problem central to both economics and psychology concerns the nature of uncertainty, or limits upon the information available for decisions. Some early theorists postulated that there are multiple types of uncertainty, while others argued that all forms of uncertainty involve similar subjective assessments of belief. Here, I present research from my laboratory that provides evidence that different forms of uncertainty in decision making have distinct neural correlates. Using functional magnetic resonance imaging (fMRI), we have found that when uncertainty changes dynamically over a short time window, lateral prefrontal and posterior parietal regions are central to its resolution. This result, which we have found for both psychophysical decisions and choices between economic gambles, contrasts with previous studies of longer-term uncertainty about stimulus-response relations, which have implicated frontomedian cortex. Additional work identifies functional dissociations between lateral prefrontal and posterior parietal regions, such that the former's activation scales with outcome uncertainty (e.g., "What will happen?") while the latter's activation increases with response uncertainty (e.g., "What should I do?"). The distinction between neural mechanisms subserving different forms of uncertainty resolution provides an important constraint for neuroeconomic models of decision making.

Title: **Neural correlates of competition within an Ultimatum Game**

Authors: Brooks King-Casas[1], Jian Li[1], Urs Fischbacher[2], Ernst Fehr[2], P Read Montague[1]

Institution: [1] Human Neuroimaging Laboratory, Baylor College of Medicine
[2] Institute for Empirical Research in Economics, University of Zurich

Address: One Baylor Plaza, S104, Houston, TX 77030

Email: bkc@hnl.bcm.tmc.edu

Abstract text (please fill no more than this page)

Objective: Recent work using two-person economic exchanges has identified different neural responses to fair and unfair offers. Further work has identified neural activity that accompanies decisions to punish economic partners that act unfairly. In the present study, we seek to investigate how competition among economic agents modulates the perception of and response to unfair offers.

Methods: We used event-related hyperscan-fMRI to image competing players engaged in a variant of the Ultimatum Game. In each exchange, one 'proposer' offered to split 10 monetary units with two 'responders'. If both 'responders' rejected the proposer's offer, no players received any monetary units. If at least one 'responder' accepted, the split was executed between the 'proposer' and any accepting 'responders'.

Results & Discussion: Behavioral analysis of 180 subjects confirms that the introduction of competition reduces rejection rates relative to the non-competitive version of Ultimatum Game. Function analysis of 40 scanned subjects within this task is ongoing. Conclusions: Preliminary results suggest that while introduction of competition mitigates the propensity to punish unfair offers, these offers nonetheless elicit increased activation of insular cortex. Further analyses are ongoing.

Acknowledgements: We thank Kristen Pfeiffer and Nathan Apple for help conducting these experiments. This work was funded by the Kane family foundation (P.R.M.) and NIDA grant DA-11723 (P.R.M.), Swiss National Science Foundation 12-67751.02 (E.F.), Ludwig Boltzmann Institute for the Analysis of Economic Growth (U.F.).

Title: **Motivation modulates memory: Neurally linking affect and cognition**

Authors: Alison Adcock, Brian Knutson, John Gabrieli

Institution: Stanford University

Address: Bldg. 420, Jordan Hall, Stanford CA 94305

Email: knutson@psych.stanford.edu

Abstract text (please fill no more than this page)
In previous research, we have reported that mesolimbic regions (including the midbrain and ventral striatum) activate proportional to anticipated monetary gain. In this study, we examined whether activation of mesolimbic regions could then modulate memory. While undergoing event-related FMRI, 12 subjects saw cues indicating that they could make either $0.05 or $5.00 for successfully remembering a scene to be presented 2-6 sec later. A day after the scan, subjects were tested for stimulus memory. Results indicate that mesolimbic activity predicted both immediate medial temporal lobe activation, as well as higher confidence memory a day later for $5.00 trials. Additionally, individuals who robustly recruited mesolimbic regions remembered more $5.00 scenes. The results suggest that expected value can modulate memory, and that this may occur via mesolimbic modulation of medial temporal lobe encoding.

Title: **Behavioral characteristics and neural correlates of decision-making under ambiguity**

Authors: Ifat Levy[1], Jason Snell[1], Aldo Rustichini[2], and Paul W. Glimcher[1]

Institution: [1] New York University, [2] University of Minnesota

Address: Center for Neural Science, NYU, 4 Washington Pl., New York, NY 10003

Email: Ifat.levy@nyu.edu

Abstract text (please fill no more than this page)
People and animals often violate expected utility theory in their decisions. Consider the following example: you are faced with two opaque urns, one containing 30 blue balls and 30 red ones and another containing 60 blue and red balls in an unknown proportion. What would you prefer – betting on the color of a ball drawn from the first urn or from the second one? In the first case, the probability for blue or red is 50%, in the second case the probabilities are not known, so that the choice is ambiguous. However, since you pick red or blue, the probability of winning is still 50%. Suppose betting on the first urn pays $5 and betting on the second pays $10. Surprisingly, some people strongly prefer the unambiguous urn even if it pays half the money. This aversion to ambiguous choices was first described by Ellsberg in 1961 and has been widely examined in the economics literature ever since. Although a strong and consistent finding, it remains largely unexplained.

Here we characterized ambiguity aversion behaviorally and then examined its neural basis using fMRI. In each trial of a behavioral experiment subjects had to choose between a constant non-ambiguous choice (50% chance of winning $5) and an ambiguous choice, which varied in both ambiguity level and reward level. Both choices were represented by urns containing colored poker chips. Ambiguity level was manipulated by occluding different portions of the urn (25%, 50%, 75% or 100%). Reward levels were indicated by a number next to the urn. Four blocks of 200 trials each were run. One trial of each block was then randomly selected and the choice made by the subject in that trial played for real money. The ambiguous lottery was preferred only when it paid much more than the unambiguous one and this ambiguity premium was a monotonic function of the level of ambiguity. To make subjects indifferent between the ambiguous and non-ambiguous choices, the 25% ambiguity payoff had to be almost 90% higher than the non-ambiguous payoff. For 50% and 75% ambiguity this payoff had to be 450% and 800% higher respectively. Neural correlates of this ambiguity premium were identified with fMRI. Initial results implicate areas in posterior parietal cortex, the insula and frontal cortex in the processing of ambiguity.

Supported by the James S. McDonnell Foundation and the Seaver Foundation

Title: **Neural correlates of reinforcement learning in Parkinson's Disease**

Authors: Jian Li[1], Michele York[2], P. Read Montague[1,3]*

Institution: [1] Department of Neuroscience, [2] Department of Neurosurgery
[3] Menninger Department of Psychiatry and Behavioral Sciences
Baylor College of Medicine

Address: 1 Baylor Plaza
Houston, Texas 77030

Email: read@bcm.tmc.edu

Abstract text (please fill no more than this page)
Dopamine (DA) depletion in the basal ganglia gives rise to cognitive deficits, including decision-making impairments in Parkinson's disease patients (PD). We use a continuous alternative decision-making task within which ongoing changes in action selection among healthy controls and PD patients was well captured by a reinforcement learning model. Changes in reward prediction errors covaried with functional MRI signal in the striatum in both groups. However, large changes in prediction errors, evident when global reward contingencies were switched, in the middle of the task were reflected in increased inferior prefrontal gyrus (IFG) activity among healthy subjects and anterior cingulate cortex (ACC) activity in mild PD patients. These results confirm that PD patients are sensitive to ongoing changes in reward prediction errors while depletion in DA may lead to an inability of the prefrontal cortex to implement novel global reward contingencies -- changes that require cognitive control -- while the ACC signals that such strategic processes are required.

Title: **An fMRI Study of Decision Making in a Trading Simulation**

Authors: Terry Lohrenz (corresponding)[1], Kevin McCabe[2], P.Read Montague[1]

Institution: [1] Baylor College of Medicine, [2] George Mason University

Address: 1 Baylor Plaza, Room S104 Houston, TX 77030

Email: tlohrenz@hnl.bcm.tmc.edu

Abstract text (please fill no more than this page)

We report on an fMRI study in which subjects made trading decisions in response to historical markets. More precisely, in this study we scanned subjects while they repeatedly adjusted their portfolios between cash and the market as market trajectories were revealed.

Title: **Effects of Rapid Tryptophan Depletion on Risk Preferences in Macaques**

Authors: Arwen Long, Allison N. McCoy, Sheila Roberts and Michael L. Platt

Institution: Duke University Medical Center

Address: Dept. Neurobiology, 431 Bryan Research Bldg., Box 3209, Duke University, Durham, NC, 27710

Email: arwen@neuro.duke.edu

Abstract text (please fill no more than this page)
Variance in reward outcomes, or risk, induces strong behavioral biases in both people and animals, even when mean rewards are constant. Thus, risk-sensitivity provides a potentially powerful assay for dissociating neural representations of reward from subjective preferences underlying decision-making. Recent work in our lab showed that rhesus macaques offered a choice between a certain reward and a variable reward more frequently chose the risky option. Low levels of the neuromodulator serotonin contribute to depression, anxiety, and impulsivity. Moreover, serotonin depletion increases responses for conditioned rewards and impairs the ability to discriminate rewards of different magnitudes. Based on these observations, we hypothesized that depleting serotonin would systematically modulate risk preferences. To study the effect of serotonin depletion on risk sensitivity, we used Rapid Tryptophan Depletion (RTD), a dietary amino acid manipulation that rapidly depresses serum tryptophan and brain serotonin levels, in macaques performing a risky choice task. RTD increased the tendency of two monkeys to make risky choices relative to matched control experiments. Enhanced preference for the risky option may have reflected reduced sensitivity to lower than average reward outcomes. Intriguingly, the spatial accuracy of both monkeys' responses was higher following RTD, but there were no systematic changes in response latency or amplitude. These results support a role for serotonin in reward-processing, attention, and risk-sensitive decision-making.

Title: **Intertemporal choice behavior in monkeys: interaction between delay to reward, subjective value, and area LIP**

Authors: Kenway Louie and Paul W. Glimcher

Institution: New York University

Address: 4 Washington Pl Rm 809, New York, NY 10003

Email: klouie@cns.nyu.edu

Abstract text (please fill no more than this page)
Studies of choice behavior show that the preference for a reward is governed by when that reward is received, a phenomenon know as delay discounting. Experiments in both animals and humans have shown that the subjective value of a reward is a consistent function of the delay to reinforcement, decreasing (or discounting) as the required wait to receive the reward increases.

It is already known that in the macaque brain, the activity of specific neurons believed to lie within decision-making circuits is correlated with the decision utility of the actions those neurons encode. Neurons within the lateral intraprietal area (LIP), a cortical area involved in the generation of eye movements, are modulated by several factors which alter the decision utility of the saccades they encode. For example if a rightward saccade yields a small but certain reward and a leftward saccade yields a larger reward with low probabilty, LIP activity will be stronger for the rightward saccade if monkeys prefer that reward. If neurons in area LIP encode the decision utilities of actions, then LIP neurons should be modulated by the delay to reinforcement if decision utility in monkeys (as measured by choice) is influenced by this delay.

While discount functions have been well characterized in pigeons and rats, little however is known about the interaction between delay and decision utility in monkeys. We investigated this phenomenon in macaques with an oculomotor delayed reward task. In each trial animals chose between a smaller immediate reward and a larger delayed reward, with the delay varying across trials in blocks. We found that monkeys exhibit consistent temporal preferences, choosing the larger reward at short delays and the smaller immediate reward at long delays. Data from different magnitudes of delayed reward were used to quantify the decrease in decision utility with increasing delay;. Fit with a standard hyperbolic model, these data show that the discount rate in monkeys is intermediate between the slower rates of humans and the faster ones of pigeons and rats. These results suggest that delay to reward modulates subjective value in monkeys, and can be used to examine the role of temporal information in decision-related activity of area LIP.

Title: **Human fMRI evidence for the neural correlates of Option Valuation Theory**

Authors: Kerstin Preuschoff, Peter Bossaerts and Steve Quartz

Institution: California Institute of Technology

Address: m/c 228-77 Caltech, Pasadena, CA 91125

Email: kerstinp@caltech.edu, pbs@hss.caltech.edu, steve@hss.caltech.edu

Abstract text (please fill no more than this page)
Neural activity in the anterior insula has been associated with novelty seeking and exploration. Option pricing theory implies that the value of novelty seeking and exploration increases with risk. We use functional imaging to show that activity in the anterior insula correlates positively with risk in a simple gambling task.

Title: **Human matching behavior in a dynamic environment**

Authors: Robb Rutledge, Brian Lau, and Paul W. Glimcher

Institution: New York University

Address: 4 Washington Pl, Rm 809, New York, NY 10003

Email: robb@cns.nyu.edu

Abstract text (please fill no more than this page)
Reinforcement learning models accurately account for monkey choice behavior during dynamic tasks based on Herrnstein's matching law experiments (Lau & Glimcher 2005; Sugrue et al. 2004). Recent experiments have begun to determine whether this is also true in humans for related tasks with stationary environments (Rustichini et al. 2005). We have developed a rapid methodology for studying human choice behavior in a similar task with a dynamic reinforcement schedule. On each round, subjects used button presses to choose one of two targets (animated crab traps). Rewards (crabs worth $0.09) for the two targets were scheduled with different independent rates. Scheduled rewards remained available until the associated target was chosen, as in the Concurrent Variable Interval (CVI) schedule of the original matching law experiments. We instituted a dynamic reinforcement schedule by varying the probability of reward associated with each crab trap in 10-16 sequential blocks of 70-150 rounds. Subjects completed 300 rounds of training with fixed and known target probabilities followed by 1600 experimental rounds, all in less than an hour.

Human choice behavior, like that of monkeys, adapted appropriately to unsignalled transitions in reward probabilities. The ratio of choices to each alternative was proportional to the ratio of rewards obtained (generalized matching) in exactly the manner previously observed in monkeys. We used a reinforcement learning model incorporating the effects of past rewards and choices to predict behavior. These models accurately predicted both steady-state and trial-by-trial choice dynamics. We found that the rewards received in the recent past (4-7 rounds) strongly influenced choice in an exponentially weighted fashion reminiscent of the Bellman equation, consistent with results obtained in monkeys performing the same task.

Reinforcement learning models are widely thought to provide insight into the roles played by the basal ganglia and decision-making areas like LIP in choice. The midbrain dopamine system has been suggested to play a critical, and now well described, role in this process. Loss of these neurons late in adulthood characterizes Parkinson's disease. We therefore predict specific reinforcement learning deficits in patients with Parkinson's disease performing this task. Specifically, we predict a decrease in the reward prediction error signal leading to a reduced influence of past rewards: a decrease in the discounting rate by which previous rewards are cumulated in establishing preference. We will address this hypothesis by a within-subject comparison of patients with Parkinson's disease performing this task both on and off dopaminergic medication.

Title: **Why are celebrities effective? An fMRI study into episodic memory effects of presenter context**

Authors: Vasily Klucharev[1,2], Guillen Fernandez[2], and Ale Smidts[1]

Institution: [1] Erasmus University, [2] F.C. Donders Centre for Cognitive Neuroimaging, Radboud University, Nijmegen

Address: Erasmus University
P.O. Box 1738
3000 DR Rotterdam
the Netherlands

Email: asmidts@rsm.nl

Abstract text (please fill no more than this page)

Presenters of consumer information, such as celebrities, are frequently used in advertising to boost the appeal of a product. Recent behavioral research shows that a celebrity is not merely a source of 'peripheral' cues (Rossiter & Smidts, 2004). The critical success factor is that the celebrity must have an immediately perceivable 'expertise hook' to the type of product he or she is hired to endorse (either as a technical expert or as an expert user).
Recent neuroimaging studies have shown various context effects on neural processing of visual information (e.g., Erk et al., 2003; Smith et al., 2004). Brain activity associated with recognition of visual stimuli was found to be modulated as a function of the emotional context associated with such stimuli. Furthermore, different emotional contexts were subserved by different processing pathways underlying the subsequent memory effects (SME).
The goal of the present research is to investigate how presenter characteristics (in particularly the expertise hook) affect neural processing of products. We use an event-related functional magnetic resonance imaging (fMRI) design to study brain responses evoked by products presented in a visual context of celebrities with or without a relevant expertise hook. In addition, SME of the expertise hook are studied.

In particular, we examine the extent to which activity in the medial temporal lobe (MTL) and inferior prefrontal cortex (PFC) reliably predict subsequent remembering for incidentally learned visual stimuli (for a review, see Paller & Wagner, 2002). Different combinations of neocortical circuits can potentially interact with the MTL as a function of the nature of the event being encoded and the context of the encoding situation (Smith et al., 2004). A number of studies showed that MTL and PFC were activated by successful recognition of famous faces as compared to strangers (e.g., Bernard et al., 2004; Leveroni et al., 2000). Furthermore, the visual context consistently activates MTL which likely reflects processing of familiar associations (Bar et al., 2003). We suggest that the presenter's expertise hook as well as other presenter characteristics modulate MTL and PFC activity during product encoding and, in turn, the memory for the product. We suggest that those memory effects are in turn related to changes of buying intention.
Twelve healthy Dutch female participants were recruited for the study. They were presented with 180 photos of well-known celebrities followed by a congruent or non-congruent objects (products for which the celebrity has or has no expertise, respectively) inside the scanner. While brain activity was assessed using event-related fMRI, subjects viewed a sequential series of randomly intermixed stimuli pairs. Each pair consisted of a celebrity followed by a congruent product (90 pairs, "hook" condition) or a non-congruent product (90 pairs, "non-hook" condition). During the subsequent recognition memory test, which was performed outside the scanner, participants saw all products again randomly intermixed with the same number of new, previously unstudied products (50% chance hit rate). In addition to the old/new recognition task, participants completed

ratings of buying intention using a 0 to 100% scale, and of presenter characteristics (e.g., familiarity, attractiveness) on 7-point bipolar scales.

The hypothesis of the effect of presenter expertise hook on the product processing is tested by a contrast of neural activity in hook versus non-hook conditions. The hypothesis of the hook effect on the product memory is tested by conducting SME contrasts (activity to successfully recognized versus forgotten products in hook and non-hook conditions). We further examine the relationship between hook-related brain activity and changes in buying intentions. Discussion of the results will focus on differences of the SME in hook and non-hook conditions in the MTL and PFC neural regions. In addition, context effects of the presenter's familiarity and attractiveness on neural responses evoked by products will be discussed.

Title: **Human Discounting functions with Non-monetary Reward**

Authors: Veit Stuphorn, Vijay C. Kannan

Institution: Johns Hopkins University

Address: The Zanvyl Krieger Mind/Brain Institute
338 Krieger Hall, 3400 N. Charles St.
Baltimore, MD 21218-2685

Email: veit@jhu.edu

Abstract text (please fill no more than this page)
Humans and animals often choose alternatives that are tempting in the short-term over alternatives that are more optimal in the long run. This self-defeating behavior runs counter to rational choice theory and classical economics. For this reason, temporal reward discounting has been extensively studied in humans and animals. These studies have demonstrated that discounting typically follows a hyperbolic function.

Most human experiments involve either real or imaginary monetary reward. This is somewhat problematic, since money is an abstract reward that only has value with respect to future consumption. For this reason, we were interested in the study of a form of reward that had to be consumed upon its delivery. For ease of presentation we chose access to "interesting/stimulating" images as the reward. We collected images in five categories: animals, paintings, women, tabloid covers, and maps. Subjects had to choose between two of these categories. Following the adjusting-delay procedure of Mazur (1988), we estimated first subjective value of the image categories and secondly the indifference point between categories.

Each trial began with the presentation of two choices on the computer screen. Each option was specified by its title, two example image thumbnails, and the waiting time in seconds. Following the subject's choice the chosen category was presented after the indicated delay period. The image was drawn randomly from a set of 200 images per category. The inter-trial interval was adjusted so that each trial has the same total length regardless of the time of reward delivery.

For each block of choices one category was associated with a constant waiting time, while the waiting time of the other category was adjusted according to the following rule. The delay time was increased when the subject had chosen the flexible category and decreased when the subject had chosen the constant category. If each category has been chosen equally often in the preceding four trials the flexible delay was not adjusted and it was taken as an estimate of the indifference point. At this point a different pair of categories was presented and a new search for an indifference point was started. Each category was paired twice with all other ones, resulting in 20 comparisons and hence 20 indifference points. In each pairing first one and than the other of the categories was associated with a flexible delay. For each subject we tested if an exponential, a hyperbolic or quasi-hyperbolic function fitted all the indifference points best.

In this way we determined the reward discounting function of humans for immediately consumable rewards. This data is one step towards bridging the gap between the existing behavioral discounting data in humans and animals.

Title: **Exchange task reveals differential neural responses across social context and gender**

Authors: Damon Tomlin[1], Brooks King-Casas[1], Cedric Anen[2], Steven R. Quartz[2], and P. Read Montague[1]

Institution: [1] Baylor College of Medicine, [2] California Institute of Technology

Address: 1 Baylor Plaza, S104
Houston, TX 77030

Email: dtomlin@hnl.bcm.tmc.edu

Abstract text (please fill no more than this page)
Important social exchanges require trust – the willingness of an investor to bet that a receiver of trust, or "trustee", will reciprocate a risky investment in a way that benefits both parties. The notion of trust elicits images of relationships, emotional entanglements, and the powerful influence of social context. Despite these complexities, trust can be simplified and studied quantitatively. The behavioral and neural substrates of trust are crucial for any understanding of social function and those contexts and disorders in which it breaks down or functions anomalously. Neuroimaging experiments have already begun to probe neural responses associated with the execution of exchange games, and recent work has uncovered specific neural responses correlated with unfairness and cooperation in social exchange tasks.
We used functional magnetic resonance imaging to probe human neural responses during a dynamic social game. Two versions of the task were implemented. In the first, subjects met before and after the experiment (n = 40 pairs); in the second, members of each subject pair participated at a different institution, in the absence of information regarding their partner (n = 48 pairs). Trust and trustworthiness were encoded as monetary units risked by an investor or returned by a trustee. We report two major differences in neural responses during this repeated exchange. The first difference was found between the two versions of the task; that is, across the dimension of social context. The second effect was found across the dimension of gender. Subjects in both roles of the game exhibited different behaviors and evoked neural responses depending upon their sex. These results indicate the impact of context upon social processes and identify the first gender-specific neural responses that underlie the neurobiology of social exchange.

Title: **The role of stimulus and reward history on updating decision making strategy in an odor mixture discrimination task.**

Authors: Naoshige Uchida and Zachary F. Mainen

Institution: Cold Spring Harbor Laboratory

Address: Cold Spring Harbor, NY 11724

Email: uchida@cshl.edu

Abstract text (please fill no more than this page)

Because environments change dynamically, the ability to continually adjust behavioral strategies is crucial for survival. Computational theories such as temporal difference reinforcement learning provide a rich framework for studying such adaptive behavior. One particularly critical factor in reinforcement learning models is the level of certainty about predictions. In a certain environment, i.e. one in which outcomes can be accurately predicted, learning should be relatively slow. In an uncertain environment, i.e. one in which outcomes are hard to predict and prediction errors are large, learning should be faster. Here, we examined the relationship between uncertainty and learning in rats, an animal model amenable to studies of neural mechanisms.

We used a two alternative forced choice odor discrimination task (Uchida and Mainen, 2003). In this task rats are trained to classify mixtures of two odorants in different proportions into two categories associated with left and right response ports. For correct choices they received water reinforcement at the response port. The category boundary was not based on an absolute physical property of the odor stimulus but is set arbitrarily by the experimenter. Therefore animals had to learn a decision boundary through reinforcement. Strikingly, examination of the effects of the recent history of stimuli, choices and rewards on subsequent decisions showed that rats biased their choices toward the most recently rewarded choice port, a so-called "win-stay" strategy, even after animals reached asymptotic overall performance levels. Thus, even in a nominally static environment, animals were dynamically updating their decision strategy.

We next tested how uncertainty affected this dynamic learning process. Animals made many more errors for mixture stimuli close to the classification boundary compared to pure stimuli further from the boundary. Thus, "difficult" stimuli near the boundary created uncertainty predicting reward and making decisions. When reward history effects were examined as a function of mixture ratio, we found that the impact of a rewarded trial was much greater after a difficult (uncertain) stimulus than for an easy (certain) stimulus. Thus, as predicted by reinforcement learning theories, dynamic learning depended not only on rewards but on the certainty of reward predictions.

We are currently using multi-electrode recordings from the orbitofrontal and olfactory cortex during this task to examine representation of key variables in this decision task at the level of individual neurons.

Title: **Hyperscanning: A system for conducting synchronized multi-subject, multi-institution neuroimaging experiments over the Internet**

Authors: J. White*, N. Apple, J. Shin, and P. R. Montague

Institution: Human Neuroimaging Laboratory, Baylor College of Medicine

Address: One Baylor Plaza S104, Houston, TX 77030

Email: jwhite@hnl.bcm.tmc.edu

Abstract text (please fill no more than this page)
The ubiquity of social exchange and the breakdown of its underlying mechanisms in many neurological and psychiatric disorders make social interaction an important field of study. To fully investigate the link between brain and behavior during a social exchange, it is necessary to simultaneously gather synchronized behavioral and imaging data from each participant. We call the execution of such simultaneous multi-subject experiments "Hyperscanning". The scarcity of neuroimaging resources and the opportunity to investigate cross-cultural social exchanges necessitates the ability to coordinate simultaneous scanning sessions across multiple institutions. Furthermore, in order to correlate behavior and brain activation among participants, sites participating in Hyperscan experiments must be synchronized so that the behavioral and imaging data gathered during the experiment can be aligned to a common timeline. Professional software developers at the Human Neuroimaging Laboratory (HNL) have created a distributed framework for executing Hyperscan experiments. The framework, called NEMO, consists of client and server components written in Java, a SQL database for storing experiment metadata and results, an experiment script execution environment based on the Jython scripting language, and pulse-sequence customizations to facilitate network-initiated scanning. To date, the NEMO installation at the HNL has been used to execute over 490 instances of 14 different multi-subject experiments, and over 2850 instances of 58 different single-subject experiments. The HNL is currently working with institutions in Germany and China to create an international Hyperscan network to investigate cross-cultural social exchanges. NEMO has been released to the public as an open-source project, and can be downloaded and installed free of charge. For more information, please visit http://www.hnl.bcm.tmc.edu/nemo.

Supported by: NIDA, NIMH, the Human Neuroimaging Laboratory at Baylor College of Medicine

Sunday, September 18

Session chaired by Mauricio Delgado

Risk and Salience

9:00 - 9:30 am	Peter Bossaerts	Markowitz in the brain	Caltech
9:30 - 10:00 am	Caroline Zink	Defining striatal activations: a signal for stimulus salience	Emory University
10:00 - 10:30 am	Camelia Kuhnen	The neural basis of financial risk-taking	Stanford University

Title: **Markowitz in the Brain**

Authors: Kerstin Preuschoff, Peter Bossaerts and Steve Quartz

Institution: California Institute of Technology

Address: m/c 228-77 Caltech, Pasadena, CA 91125

Email: kerstinp@caltech.edu, pbs@hss.caltech.edu, steve@hss.caltech.edu

Abstract text (please fill no more than this page)
According to expected utility theory, organisms must utilize representations of both expected reward and risk to establish preferences over uncertain outcomes. To determine how these quantities are encoded in the human brain, we used a simple gambling task that varied expected reward and risk simultaneously and orthogonally across the full range of probabilities. Here, risk is measured by variance of payoff, as in Markowitz' theory. Functional magnetic imaging (fMRI) revealed signals in dopaminoceptive structures, that vary linearly with probability, expected reward, and quadratically with probability, risk. These results broaden the reward-related role of dopaminoceptive structures by demonstrating that they encode separately the two central parameters of expected utility theory.

Title: **Defining Striatal Activations: A Signal For Stimulus Salience**

Authors: CF Zink, G Pagnoni, J Chappelow, ME Martin-Skurski, GS Berns

Institution: Emory University

Address: Dept of Psychiatry & Behavioral Sciences
101 Woodruff Circle, WMB Suite 4000
Atlanta, GA 30322

Email: czink@emory.edu

Abstract text (please fill no more than this page)

The human striatum responds to a variety of stimuli categorically defined as salient, but the interpretation of such activations is widely debated, specifically whether striatal activations reflect a reward-related signal exclusively, or more generally reflect stimulus salience. Salient stimuli are characterized by their capability to perturb and seize limited cognitive resources. Using event-related functional magnetic resonance imaging (fMRI), we measured activity in the brains of 20 participants performing a visual classification task in which they identified single digits as odd or even numbers. An auditory tone preceded each number, which was occasionally, and unexpectedly, substituted by a novel sound. We were particularly interested in the brain response to the novel sounds, which varied in their ability to interrupt and reallocate cognitive resources (i.e., their saliency) as measured by a delay in reaction time to immediately subsequent numerical task-stimuli. The present findings demonstrate that striatal activity increases proportionately to the degree to which an unexpected stimulus interferes with the current focus of attention and behavior, even in the absence of reward. Activity in the bilateral caudate significantly increased following the novel sounds in a fashion that was proportional to the reaction times to the subsequent numbers. The nucleus accumbens responded similarly, but at a slightly less stringent threshold. These results suggest that activity in the human striatum signifies the level of saliency associated with a stimulus, perhaps providing a signal to reallocate limited resources to important events. As such, the so-called "reward response" of the striatum may be more accurately, and more generally, classified as a "saliency response," especially in the absence of an obvious reward.

Title**: The Neural Basis of Financial Risk-Taking**

Authors: Camelia M. Kuhnen[1] and Brian Knutson[2]

Institution: [1] Stanford Graduate School of Business and [2] Department of Psychology, Stanford University

Address: [1] Stanford Graduate School of Business, 518 Memorial Way, #S479, Stanford, CA 94305-5015. [2] Department of Psychology, Bldg. 420, Jordan Hall, Stanford University, Stanford, CA 94305.

Email: [1] camelia@stanford.edu. [2] knutson@psych.stanford.edu

Abstract text (please fill no more than this page)
Different accounts suggest that one or two systems underlie risky choice. We used event-related fMRI to investigate whether neural activity in separable systems preceded risk-seeking and risk-averse choices in a financial decision-making task. Subjects showed both optimal choices and suboptimal choices (or "mistakes"), relative to the investment strategy of a rational, risk-neutral agent. Here, we show that nucleus accumbens activation preceded risk-seeking choices and risk-seeking mistakes, while insula activation preceded risk-averse choices and risk-averse mistakes. These findings suggest that distinct anticipatory neural mechanisms promote different types of financial choices, and that excessive activity of these circuits may lead to investing mistakes.