Behavioral and Neurobiological Evidence for Probabilistic Sophistication

Mathieu d'Acremont[1], Eleonora Fornari[2], and Peter Bossaerts[1]

[1]Humanities and Social Sciences, Caltech, USA

[2]Center for Biomedical Imaging, University of Lausanne, Switzerland

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

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

Griet Emonds,[1] Carolyn H. Declerck,[2] Christophe Boone,[3] Ruth Soerinck,[4] & Rik Achten[5]

[1,2,3] University of Antwerp, Belgium

[3,4] GIFMI, University of Ghent, Belgium

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

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

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

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

Neural Computations underlying Strategic Learning

Lusha Zhu,[1] Kyle Mathewson,[2] and Ming Hsu.[3*]

[1]Department of Economics, University of Illinois at Urbana-Champaign
[2]Beckman Institute, University of Illinois at Urbana-Champaign
[3] Haas School of Business, University of California, Berkeley

[*]Correspondence at: mhsu@haas.berkeley.edu

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

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

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

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

Acknowledgements: Support from the Beckman Institute is gratefully acknowledged.

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

Warren K. Bickel [*], Jeffery A. Pitcock

University of Arkansas for Medical Sciences, Department of Psychiatry, Center for Addiction Research, Fred & Louise Dierks Research Laboratories, Psychiatric Research Institute, Little Rock, AR USA

[*]Correspondence at: WBickel@uams.edu

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

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

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

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

Acknowledgements:
Funding through NIDA grant R01DA024080, NIH grant UL1RR029884, Wilbur Mills Chair Endowment, and in part by the Arkansas Biosciences Institute, a partnership of scientists from Arkansas Children's Hospital, Arkansas State University, the University of Arkansas-Division of Agriculture, the University of Arkansas, Fayetteville, and the University of Arkansas for Medical Sciences. The Arkansas Biosciences Institute is the major research component of the Tobacco Settlement Proceeds Act of 2000.

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

D. Levy[1*] and P.W. Glimcher[1]

[1]Center for Neural Science, New York University.

[*]Correspondence to: dino.levy@nyu.edu

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

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

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

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

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

L. Amsel [1] and A.Pilpel.[2]

[1]Department of Psychiatry, Columbia University. [2]Department of Philosophy, Haifa University

[1]Correspondence at: lva2@columbia.edu

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

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

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

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

Noradrenaline in decision-making: pupil dilation reflects unexpected uncertainty

K. Preuschoff,[1*] B.M. 't Hart[2], W. Einhäuser[2]

[1]Institute for Empirical Research in Economics and Laboratory for Social and Neural Systems Research, University of Zurich, Switzerland; [2]Department of Neurophysics, Philipps-University Marburg, Germany.

[*]Correspondence at: preuschoff@iew.uzh.ch

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

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

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

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

Acknowledgements:
This study was funded by the DFG, grants # EI 852/1 (WE) and GRK-885 (BM'tH), and was supported by the Neurochoice Project of SystemsX.ch (KP).

Neural Correlates of Anticipation Risk Reflect Risk Aversion

S. Rudorf[1*], K. Preuschoff[2], C. E. Elger[1], and B. Weber[1].

[1]Center for Economics and Neuroscience, University of Bonn, Germany; [2]Institute for Empirical Research in Economics, University of Zurich, Switzerland

[*]Correspondence at: rudorf@uni-bonn.de

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

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

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

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

References:
Christopoulos et al. (2009). J Neurosci.
Cohen et al. (2010). Nat Neurosci.
Gianotti et al. (2009). Psychol Sci.
Preuschoff et al. (2006). Neuron.
Preuschoff et al. (2008). J Neurosci.
Mohr et al. (2010). J Neurosci.

Prior and likelihood uncertainty are differentially represented in the human brain

Iris Vilares[1*], James D Howard[2], Hugo L Fernandes[1], Jay Gottfried[2,3] and Konrad Kording[1,4,5]

** Correspondence at: iris-vilares@northwestern.edu*

[1] Department of Physical Medicine and Rehabilitation, Northwestern University and Rehabilitation Institute of Chicago
[2] Department of Neurology, Northwestern University
[3] Cognitive Neurology & Alzheimer's Disease Center, Northwestern University
[4] Department of Physiology, Northwestern University
[5] Department of Applied Mathematics, Northwestern University

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

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

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

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

Acknowledgements: This study was funded by Gulbenkian Foundation, the Champalimaud Foundation, the Portuguese Foundation for Science and Technology and the Chicago Community Trust.

Motivational and Neural Differences in Reward and Risk Anticipation

John A. Clithero[1,3,*], R. McKell Carter[3], Vinod Venkatraman[2,3], David V. Smith[2,3], and Scott A. Huettel[2,3]

Departments of [1]Economics and [2]Psychology and Neuroscience; [3]Center for Cognitive Neuroscience; Duke University, Durham, NC

[*]Correspondence at: john.clithero@duke.edu

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

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

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

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

Acknowledgements: Funding for this project has been provided by an Incubator Award from the Duke Institute for Brain Sciences (SAH), NIH RC1-MH88680 (SAH), and by NRSA F31-MH86255 (JAC) and F31-MH86248 (DVS).

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

Holger Gerhardt,[1, 2, 3, *] David Danz,[3, 4] Guido Biele,[5, 6]
Harald Uhlig,[7] Dorothea Kübler,[3, 4, 8] and Hauke R. Heekeren[1, 3, 5, 6, 9]

[1] Berlin School of Mind and Brain; [2] Humboldt-Universität zu Berlin, School of Business and Economics; [3] SFB 649 "Economic Risk"; [4] WZB—Social Science Research Center Berlin; [5] Freie Universität Berlin, Department of Educational Science and Psychology; [6] Max Planck Institute for Human Development, Max Planck Research Group "Neurocognition of Decision Making"; [7] University of Chicago, Department of Economics; [8] Technische Universität Berlin, Faculty VII: Economics and Management; [9] Cluster of Excellence "Languages of Emotion"

[*] Correspondence at: gerhardt@wiwi.hu-berlin.de

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

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

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

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

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

Stochastic choice behavior predicted by the BOLD signal

Stephanie C. Lazzaro, Robb B. Rutledge, Daniel Burghart, Ifat Levy and Paul W. Glimcher

Center for Neural Science, New York University

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

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

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

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

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

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

Camelia M. Kuhnen[1], Brian Knutson[2], Gregory R. Samanez-Larkin[2]

[1]Kellogg School of Management, Northwestern University

[2] Department of Psychology, Stanford University

Abstract

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

Contact & presenting author: Camelia M. Kuhnen, email: c-kuhnen@kellogg.northwestern.edu.

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

O.A. Mullette-Gillman,[1-2*] E. McClaurin,[2] K.M. Schiabor, R. Phillips, A. Robinson,[4] E.T. Cirulli,[3] D. Goldstein,[3] M. Platt,[1-2,4] J.H.P. Skene,[2,4] and S.A. Huettel[1-2,5]

[1]Center for Neuroeconomic Studies, [2]Center for Cognitive Neuroscience, [3]Department of Molecular Genetics & Microbiology, [4]Department of Neurobiology, [5]Department of Psychology and Neuroscience, Duke University

[*]Correspondence to: mullette-gillman@biac.duke.edu

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

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

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

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

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

Acknowledgements: This study was funded by an Incubator Award from the Duke Institute for Brain Sciences and by NIMH RC1-088680.

Social Components of Motivated Deception

R.M. Carter,[1,2*] D.L. Bowling[3], and S.A. Huettel.[2]
[1]Psychology and Neuroscience, Duke University; [2]Center for Neuroeconomic Studies, Duke University;
[3]Department of Neurobiology, Duke University

[*]Correspondence at: mckell.carter@duke.edu

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

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

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

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

Acknowledgements:
This work was supported by NIMH R01-070685 and by NINDS P01-41328.

Title: An Expected Utility Maximizer Walks Into A Bar

Authors: Daniel R. Burghart, Stephanie Lazzaro, Paul W. Glimcher

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

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

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

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

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

A Neural Model of Stochastic Behaviour Applied to Mixed Strategy Games

Ryan Webb
Queen's University, Canada

Abstract

September 16, 2010

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

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

Shan Luo[1,3], George W. Ainslie[4], Drusus Pollini[1], Lisa Giragosian[1] , John R. Monterosso[1,2,3 *]

[1]Department of Psychology, University of Southern California; [2] Neuroscience Graduate Program, University of Southern California; [3]Brain and Creativity Institute, University of Southern California; [4]Coatesville VA Medical Center, Coatesville PA

*Correspondence to: johnrmon@college.usc.edu

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

Acknowledgment: This work was supported by the National Institute of Health R01DA023176 (JM).

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

David Paulsen[1,2,3], McKell Carter[2,3], Michael Platt[2,3,5], Scott Huettel[1,2,3,4], Elizabeth Brannon[1,2,3]

[1]Psychology & Neuroscience, Duke University, [2]Center for Cognitive Neuroscience, Duke University, [3]Center for Neuroeconomic Studies, Duke University, [4]Brain Imaging and Analysis Center, Duke University, [5] Department of Neurobiology, Duke University

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

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

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

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

Acknowledgments:
Funding for this study was provided by the Duke Institute for Brain Sciences and NIMH RC1-88680 to SH and EB.

Spontaneous lies in social contexts are associated to reduced motor readiness

Panasiti MS[1]*, Pavone EF[1,2], Mancini A[1], Merla A[3], Aglioti SM[1,2]

1 Psychology Department, Sapienza, University of Rome
2 IRCCS Santa Lucia Foundation, Rome
2 Institute for **Advanced Biomedical Technologies , G. d'Annunzio, Univeristy of Chieti**

* m.serenapanasiti@gmail.com

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

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

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

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

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

David V. Smith[1,2,3], John A. Clithero[1,2,4], Sarah E. Boltuck[1], Scott A. Huettel[1,2,3]*

[1]Center for Cognitive Neuroscience; [2]Center for Neuroeconomic Studies;
[3]Departments of Psychology and Neuroscience; and [4]Economics
Duke University, Durham, NC 27708

Correspondence at: david.v.smith@duke.edu

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

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

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

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

Acknowledgments
This study was funded by an Incubator Award from the Duke Institute for Brain Sciences (SAH), and by NIMH National Research Service Awards F31-086255 (JAC) and F31-086248 (DVS).

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

C. Buerger[1], J. Weghmann[2] and B. Weber[1]

[1]Center for Economics and Neuroscience, University of Bonn, Germany
[2]Faculty of Psychology and Neuroscience, Maastricht University, The Netherlands

Correspondence: Corinna.Buerger@ukb.uni-bonn.de

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

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

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

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

Optimal Information Integration in a Hierarchical Decision Task

Ulrik Beierholm[1*], Klaus Wunderlich[2], Peter Bossaerts[2,3,4] and John P O'Doherty[2,3,5]

[1] Gatsby Computational Neuroscience Unit, UCL, London, UK; [2] Computation and Neural Systems Program, California Institute of Technology, Pasadena, CA; [3] Division of Humanities and Social Sciences, California Institute of Technology, Pasadena, CA; [4] Ecole Polytechnique Federale de Lausanne, Swiss Confederation; [5] Trinity College Institute of Neuroscience and School of Psychology, Trinity College, Dublin, Ireland.

[*]Correspondence at: beierh@gatsby.ucl.ac.uk

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

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

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

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

Acknowledgements:
This study was funded by grants from the Gordon and Betty Moore Foundation to JOD, a Gordon and Betty Moore Foundation Scholarship to KW, a Marie Curie European reintegration grant to UB, a Searle Scholarship to JOD, and the Caltech Brain Imaging Center and the Gatsby Charitable Foundation

Strategic and Social Decision-Making Mechanisms Support Language Processing

C. T. McMillan[1*], R. Clark[2], D. Gunawardena[1], M. Dreyfuss[1], and M. Grossman[1]

[1]Department of Neurology, University of Pennsylvania; [2]Department of Linguistics, University of Pennsylvania

[*]Correspondence at: mcmillac@mail.med.upenn.edu

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

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

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

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

Acknowledgements:
This study was funded by the NIH, grant HD060406, AG17586, AG15116, NS44266, and NS53488.

Double asymmetry of reciprocity: a behavioral and neurobiological study

A. Riedl[1], S. Okamoto-Barth[1,2], M. Strobel[1], A. Heinecke[3], H. Breman[3], and R. Goebel[2,3]

[1]Department of Economics, School of Business and Economics, Maastricht University; [2]Department of Cognitive Neuroscience, Faculty of Psychology and Neuroscience, Maastricht University; [3]Brain Innovation B.V., Maastricht, the Netherlands.

[*]Correspondence at: a.riedl@maastrichtuniversity.nl

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

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

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

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

Acknowledgements:
This study was funded by NWO, grant # 051.07.008.

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

Joshua Sanders, and Adam Kepecs*

Cold Spring Harbor Laboratory and Watson School for Biological Sciences, Cold Spring Harbor, NY

*Correspondence at: kepecs@cshl.edu

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

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

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

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

Acknowledgements:
This study was funded by the Whitehall and Klingenstein Foundations.

Value transfer in human sensory preconditioning with monetary reinforcement

G. Elliott Wimmer and Daphna Shohamy

Department of Psychology, Columbia University

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

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

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

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

Acknowledgements:

This study was funded by NIH/NIDA (grant #1R03DA026957 to D.S.)

The Neural Basis of Expectations in Social-Bargaining

Luke J. Chang,[1*], Alec Smith[2], and Alan G. Sanfey[1,3]

[1]Department of Psychology, University of Arizona; [2]California Institute of Technology, [3]Donders Institute for Brain, Cognition, and Behaviour.

[*]Correspondence at: ljchang@email.arizona.edu

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

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

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

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

Acknowledgements:
This study was funded by the NIA - R21AG030768 and the NIMH - F31MH085465-01A1.

Neural correlates of the influence of extrinsic rewards on intrinsic motivation

K. Albrecht,[1*] J. Abeler[2], B. Weber[1], and A. Falk[1]

[1]University of Bonn, [2]University of Nottingham

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

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

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

The Minimax Matching Hypothesis

Liam Clegg
Department of Economics, Tufts University

Liam.Clegg@tufts.edu

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

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

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

Acknowledgements:
This research was made possible by Tufts University

The Neural Basis of Wage Valuation in Economic Search Under Uncertainty

J. Heinonen[1], J. Suomala[1*], L. Palokangas[1] and J. Numminen.[2]

[1] Laurea University of Applied Sciences, Finland; [2] Hospital District of Helsinki and Uusimaa, Finland

[*]Correspondence at: Jyrki.Suomala@Laurea.fi

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

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

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

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

ABSTRACT

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

Dante M. Pirouz
University of Western Ontario
Richard Ivey School of Business
London, ON N6A 3K7
(949) 331-8976, dpirouzmerage@gmail.com

Cornelia (Connie) Pechmann
University of California, Irvine
Paul Merage School of Business
Irvine, CA 92619

Paul F. Rodriguez
University of California, San Diego
Multimodal Imaging Laboratory
La Jolla, CA 92037

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

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

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

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

Katya Rascovsky[1*], Corey T. McMillan[1], Peachie Moore[1], Robin Clark[2], Brianna Morgan[1] and Murray Grossman[1]

[1] University of Pennsylvania School of Medicine, Department of Neurology

[2] University of Pennsylvania, Department of Linguistics

* Corresponding Author: katyaras@mail.med.upenn.edu

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

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

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

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

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

Acknowledgements: This work was supported by the following grants from the National Institutes of Health: AG17586, AG15116, NS44266 and NS53488.

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