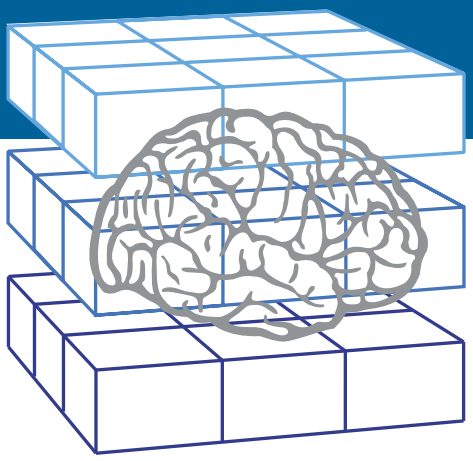
Society for
NeuroEconomics
NEUROSCIENCE • PSYCHOLOGY • ECONOMICS

13TH ANNUAL MEETING PROGRAM

NEUROECONOMICS: DECISION MAKING AND THE BRAIN

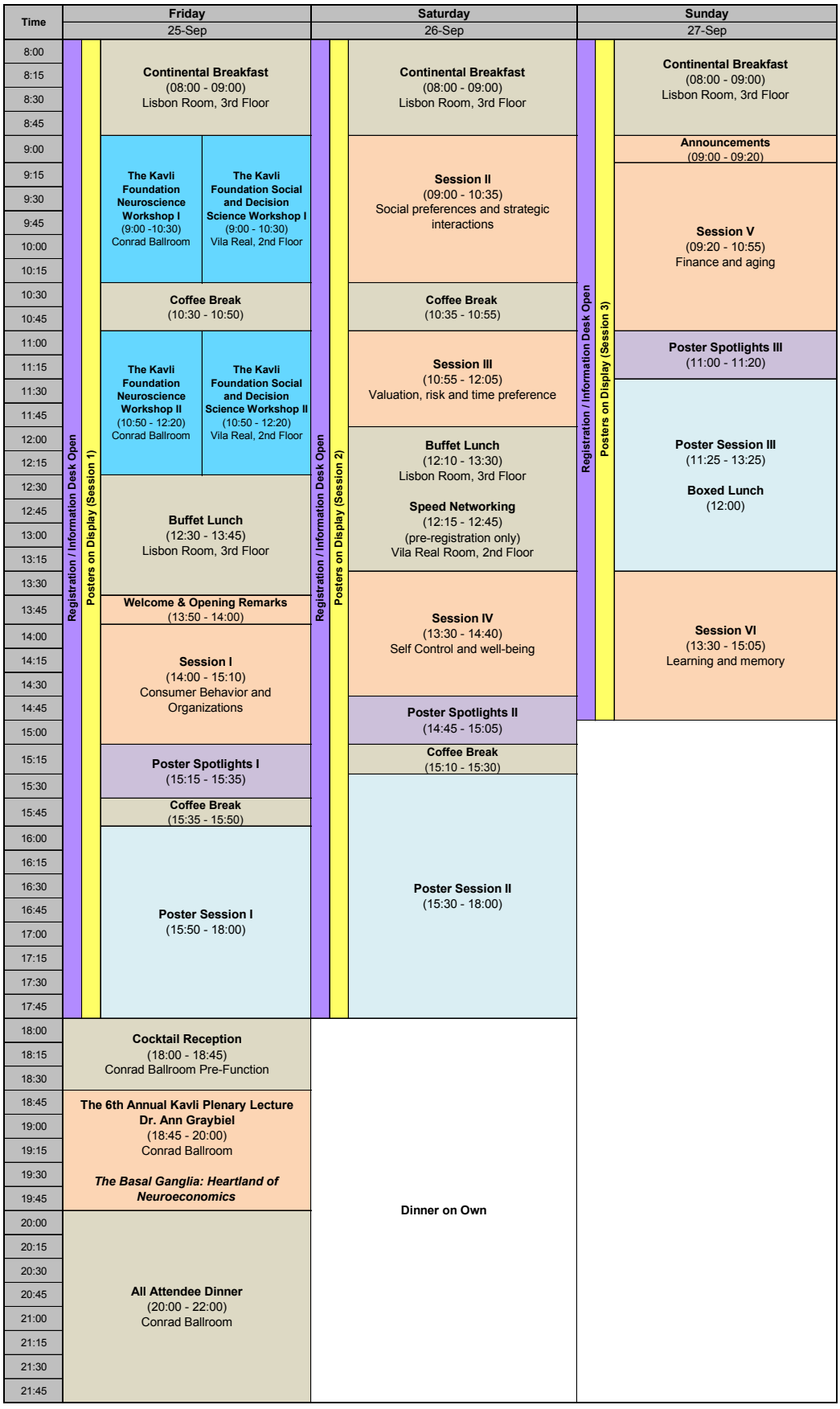


September 25 – 27, 2015

Miami, Florida
Conrad Miami Hotel

www.neuroeconomics.org

PROGRAM AT A GLANCE



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OUR MISSION

The mission of the Society for Neuroeconomics is to:

Foster research on the foundations of economic behavior by promoting collaboration and discussion among scholars from the psychological, economic, and neural sciences.

Ensure the continued advancement of the field of neuroeconomics by supporting young researchers.

The Society promotes this mission through annual meetings for presentation of original theory and research, and through educational programs to promote development of a common language and set of methodological tools for the field.

SOCIETY FOR NEUROECONOMICS BOARD OF DIRECTORS

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GENERAL CONFERENCE INFORMATION

Meeting Venue

Conrad Miami Hotel
Espirito Santo Plaza, 1395 Brickell Avenue
Miami, FL 33131

Registration

The annual meeting of the Society for Neuroeconomics registration includes admission to all sessions, a printed abstract booklet, access to breakfast, coffee breaks, lunches and The 6th Annual Kavli Plenary lecture and dinner as well as to all the sessions and workshops. Kindly wear your name badge at all time as your admission to the sessions and meals. At the end of the conference you are encouraged to recycle your badge at any of the recycle stations or registration desk when you leave.

Registration and information desk

The registration/information desk, located in the Conrad Pre-Function Hallway is open daily during conference session hours:

Friday, September 24	7:30 – 18:00
Saturday, September 25	7:30 – 18:00
Sunday, September 26	7:30 – 15:00

Wireless Internet

Complimentary wireless internet is available to the delegates of the Society of Neuroeconomics Annual Meeting. Please choose either the **attwifi** or **hhonors** networks and enter the code: **SNE2015!** Complimentary wireless is available throughout the meeting rooms and guest rooms of the hotel.

Hotel Floor Plan

Miami Information

Please visit the registration desk to pick up a copy of a Delegate's Guide to Miami which includes maps of the surrounding areas, suggestions of things to visit and areas of interest. During the conference Miami is also celebrating Miami Spice – when restaurants offer three-course meals featuring signature dishes created by world-renowned chefs at reduced prices. A list of participating restaurants can be found on the Miami Visitors Bureau website (*www.miamiandbeaches.com/special-offers/monthly-deals/miami-spice-month*) .

Staff

SNE staff from Podium Conference Specialists and the SNE administrative team can be identified by the orange ribbons on their name badges. Feel free to ask any one of our staff for assistance, or visit the registration desk.

Poster Sessions

Please visit our poster presenters during the three poster sessions. Coffee and tea will be served immediately before the poster sessions on Friday and Saturday, please feel free to enjoy your beverage while enjoying the posters. The posters are spread amongst three rooms (the Porto, Faro and Algarve Rooms) and the hallway. Information on Poster Authors, Poster Numbers and Poster Titles begins on page 14. For a complete copy of the poster abstracts, please see the appropriate section of the abstracts later in this program.

Poster Session 1

Set Up: Friday September 25, 2015 between 08:00 and 09:00
Session Time: 15:50 – 18:00
Tear Down: 18:00 – 22:00

Poster Session 2

Set Up: Saturday September 26, 2015 between 08:00 and 09:00
Session Time: 15:30 – 18:00
Tear Down: 18:00 – 20:00

Poster Session 3

Set Up: Sunday September 27, 2015 between 08:00 and 09:00
Session Time: 11:25 – 13:25
Tear Down: 13:30 – 16:00

DETAILED PROGRAM

Friday, September 25, 2015

The Kavli Foundation Neuroscience Workshop

Conrad Ballroom, 3rd Floor

SESSION I:
9:00 – 10:30

The expected value of control: An integrative theory of motivation, effort and controlled processing

Jonathan Cohen *Princeton University*

The dorsal anterior cingulate cortex (dACC) has been a near-ubiquitous presence in three literatures directly relevant to the neuroscience of decision making; those on cognitive control, value-based decision making, and motivation. However, much less attention has been given to how its function in each of these domains may relate to its function in the others. In this talk I will describe a theory, inspired by a consideration of these literatures and the role that dACC plays within them, that addresses how value-based decisions impact and, in turn, are impacted by cognitive control. This theory posits that the primary function of dACC is to compute the expected value of candidate, control-demanding behaviors (the expected value of control, or EVC), and to select for execution (through the allocation of control) those that maximize this quantity. The theory builds on standard models of reward optimization (in both learning and decision making), taking into account the costs inherent to the allocation of control itself. It provides a coherent, and formally explicit framework for considering how the allocation of control — informed by a cost/benefit analysis of available options — impacts decision making and behavior. I will review behavioral and neuroscientific data in support of the theory, and present simulation results that demonstrate the model's ability to capture many of these findings.

10:30 – 10:50 Coffee Break

SESSION II:
10:50 – 12:20

Norepinephrine and neural gain

Mara Mather *USC Davis School of Gerontology*

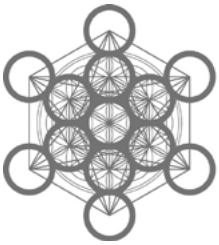
It has long been recognized that a key function of the locus coeruleus-norepinephrine system is to adjust the gain on information processing in the brain, such that increasing levels of norepinephrine under arousal are associated with amplification of 'signal' and suppression of 'noise'. But it has not been clear how norepinephrine can turn the knob on gain. How can this neurotransmitter, released broadly across much of the brain under arousal, have opposite effects on different types of neural representations? In this talk I review the basic mechanisms of norepinephrine and present a model of how it modulates neural gain. This model helps explain how emotional arousal can either enhance or impair attention and memory, depending on information priority.

The Kavli Foundation Social and Decision Science Workshop

Vila Real, 2nd Floor

SESSION I: **9:00 – 10:30**	***Behavioral Finance: Progress and Challenges*** **Nicholas Barberis** *Yale School of Management* The field of behavioral finance argues that many important financial phenomena are the result of less than fully rational thinking on the part of some market participants. Over the past 20 years, the field has grown dramatically in both content and visibility, and is by far the most developed area of behavioral economics. Using models of human behavior that are firmly grounded in psychology, researchers in the field have tackled topics such as fluctuations in financial markets, asset bubbles, investor trading behavior, and merger and acquisition activity. This talk provides an overview of behavioral finance – its progress, its core ideas, and the challenges it faces – and also discusses some areas of potential collaboration between researchers in behavioral finance and researchers in neuroscience.
10:30 – 10:50	Coffee Break
SESSION II: **10:50 – 12:20**	***Genoeconomics*** **David Laibson** *Harvard University* The genetic architecture of economic behavior is characterized by millions of genetic loci that each have a small effect on a phenotype of interest. For example, the most influential single-nucleotide polymporhisms each explain less than 1/10 of 1% of the variance in educational attainment. However, when those effects are aggregated and tested out-of-sample, (linear) polygenic risk scores explain 5%-15% of cross-sectional variance in behavior. In this talk, I'll summarize the molecular genetic methods that have been used to draw such conclusions and discuss the future direction of genoeconomics research.
12:30 – 13:45 Lisbon Room, 3rd Floor	Lunch Sponsored in part by **Columbia University Center for Decision Sciences and Columbia Business School**
WELCOME AND OPENING REMARKS 13:50 – 14:00	**Camelia Kuhnen** *President*
SESSION I **14:00 – 15:10**	***Consumer Behavior and organizations*** Chair: **Camelia Kuhnen**
14:00 – 14:20	***Influencing cognitive control: the effect of social pressure vs. monetary incentives*** **Sergeja Slapnicar** Mina Godec, Sergeja Slapnicar, Frank Hartmann, Anka Slana, Grega Repovs
14:25 – 14:45	***Multivariate encoding of neural responses to movie-trailers is associated with individual evaluation and predictive of commercial success*** **Hang Yee Chan** Hang-yee Chan, Vincent Schoots, Alan Sanfey, Ale Smidts, Maarten Boksem

14:50 – 15:10	***Neural prediction of crowdfunding decisions*** **Alexander Genevsky** Alexander Genevsky, Carolyn Yoon, Brian Knutson
POSTER SPOTLIGHTS I **15:15 – 15:35**	Chair: **Ale Smidts**
	A valuation-based mechanism for increased apathy following ventromedial prefrontal damage **Jeremy Hogeveen** Jeremy Hogeveen, Katherina K. Hauner, Frank Krueger, Jordan Grafman
	Oxytocin influences taste placebo effects **Laura Enax** Laura Enax, Hilke Plassmann, Sabrina Strang, Holger Gerhardt, Rene Hurlemann, Dirk Scheele, Nina Marsh, Bernd Weber
	Interrupt the Impulse: Lateral prefrontal cortex function is necessary for optimal choice **Marian Sauter** Marian Sauter, Alexander Soutschek, Torsten Schubert
	Effort, reward, and vigor in decision-making and motor control **Alaa Ahmed** Reza Shadmehr, Helen Huang, Alaa Ahmed
	Patients with Parkinson's Disease Fail to Use Memory to Guide Decisions Independent of Feedback **Alessandra Perugini** Alessandra Perugini, Michele A. Basso
15:35 – 15:50	Coffee Break
POSTER SESSION 1 **15:50 – 18:00**	Please visit our poster presenters in the Porto, Faro and Algarve rooms. A full list of poster presenters can be found further in the conference program. Co-Sponsored by **The Duke Institute for Brain Sciences & the Duke Center for Interdisciplinary Decision Sciences** and **INSEAD Center for Decision-Making and Risk Analysis**



THE KAVLI FOUNDATION

6th Annual Kavli Lecture

18:00 – 18:45	Cocktail reception Co-Sponsored by **The Interdisciplinary Center for Economic Science (ICES)** and the **Center for the Study of Neuroeconomics (CSN) at George Mason University**
18:55 – 20:00	The 6th Annual Fred Kavli Foundation Plenary Lecture ***The Basal Ganglia: Heartland of Neuroeconomics*** **Dr. Ann Graybiel** *Massachusetts Institute of Technology* Regions of the medial prefrontal cortex are known to function in organizing behavior and emotional decision-making, both key functions disturbed in a range of neurologic and neuropsychiatric disorders. In our laboratory, we are seeking to understand mechanisms underlying these functions by applying optogenetic manipulations and microstimulation to these regions and their corticostriatal circuits. We find that we can interrupt the transition from deliberative decision-making to a habitual mode of decisions to act, and can interrupt habitual and insistently repetitive behaviors. In other experiments, we can selectively disrupt decision-making under different contexts involving weighing the costs and benefits of such choices. These experiments point to profoundly important functions of corticostriatal circuits and to their exquisite specialization. These features could be critical in linking these corticostriatal circuit mechanisms to human disorders in which value-based decision-making is affected.
20:00 – 22:00	Buffet Dinner Sponsored in part by **New York University Institute for the Interdisciplinary Study of Decision Making**

Saturday, September 26, 2015

SESSION II **09:00 – 10:35**	***Social preferences and strategic interactions*** Chair: **Ian Krajbich**
9:00 – 9:20	***Low frequency rTMS to monkey STS moderates neuronal sensitivity to social reward*** **Amanda Utevsky** Utevsky, A. V., Platt, M.L
9:25 – 9:45	***Basolateral amygdala lesions abolish mutual reward preference in rats*** **Tobias Kalenscher** Tobias Kalenscher, Marijn van Wingerden, Sandra Schäble, Julen Hernandez-Lallement
9:50 – 10:10	***Neural Adaptation Mediates Escalation in Dishonesty*** **Tali Sharot** Neil Garrett, Stephanie Lazzaro, Dan Ariely, Tali Sharot
10:15 – 10:35	***A causal account of the neural computations in TPJ subserving strategic choice in competitive social interactions*** **Christopher Hill** Christopher A. Hill, Shinsuke Suzuki, Rafael Polania, Marius Moisa, John P. O'Doherty, Christian C. Ruff
15:35 – 15:55	Coffee Break
SESSION III **10:55 – 12:05**	***Valuation, risk and time preference*** Chair: **Paul Glimcher**
10:55 – 11:15	***Expected Subjective Value Theory: A Representation of Decision in Time Under Risk*** **Agnieszka Tymula** Agnieszka Tymula, Paul Glimcher
11:20 – 11:40	***Intertemporal Choice and Valuation are Influenced by the Attraction Effect*** **Sebastian Gluth** Sebastian Gluth, Jörg Rieskamp
11:45 – 12:05	***Category-independent value and salience signals in the human brain*** **Zhihao Zhang** Zhihao Zhang, Daniel B. Ehrlich, Jennifer Fanning, Wenting Chen, Daeyeol Lee, Ifat Levy

SPEED NETWORKING **12:15 – 12:45** Vila Real Room, 2nd Floor	If you signed up in advance for the Speed Networking event, please proceed directly to the Vila Real Room on the second floor immediately after Session III. Lunch will be available at 12:45 following the Speed Networking Sponsored by the **Department of Economics at the University of Zurich**
12:10 – 13:30 Lisbon Room, 3rd Floor	Lunch Sponsored in part by **UNC Kenen-Flagler Business School**
SESSION IV **13:30 – 14:40**	***Self control and well-being*** Chair: **Brian Knutson**
13:30 – 13:50	***Dietary self-regulation is linked to individual differences in serum leptin and delay discounting for food but not money in lean participants*** **Liane Schmidt** Liane Schmidt, Judith Aron-Wisnewski, Nicolas Manoharan, Michèle Chabert, Armelle Leturque, Karine Clement, Christine Poitou-Bernert, Hilke Plassmann
13:55 – 14:15	***Self-control signals in medial frontal cortex of monkeys during a temptation task*** **Veit Stuphorn** Jaewon Hwang, Erik E. Emeric, Veit Stuphorn
14:20 – 14:40	***Disrupted Cortical Regulation of Striatal Value Signals Drives Self-Control Deficits in Incarcerated Criminal Psychopaths*** **Joshua Buckholtz** Jay Hosking, Erik Kastman, Hayley Dorfman, Arielle Baskin-Sommers, Joseph P. Newman, Kent Kiehl, Joshua W. Buckholtz
POSTER SPOTLIGHTS II **14:45 – 15:05**	Chair: **Joe Kable**
	Neural Subjective Value Representations Depend on Decision Features: Time Delay, Physical Effort, and Probability Discounting **Nickolas Brooks** Nickolas Brooks, Marissa A Gorlick, Todd A Hagen, Vanessa Holman, Linh Dang, Ming Hsu, David H Zald, Gregory R Samanez-Larkin
	The spillover effects of attentional learning on value-based choice **Rachael Gwinn** R. Gwinn, A. Leber, I. Krajbich
	Decreasing inequality aversion with non-invasive brain stimulation **Giuseppe Ugazio** Giuseppe Ugazio, Christopher Burke, Christian C. Ruff, Philippe N. Tobler
	Timing of value representation in ventromedial prefrontal cortex in a complex auction task **Linda Yu** L. Q. Yu, N. Cooper, G. Zauberman, B. K. Kim, J. W. Kable

	A dynamic threshold model of optimal stopping **Silvio Ravaioli** S. Ravaioli, L. Polonio, M. Sodini, G. Coricelli
	Chronic and acute stress promote over-exploitation in foraging decisions **Jennifer Lenow** J.K. Lenow, S.M. Constantino, N.D. Daw, E.A. Phelps
15:10 – 15:30	Coffee Break
POSTER SESSION II **15:30 – 18:00**	Please visit our poster presenters in the Porto, Faro, and Algarve Rooms. A full list of poster presenters can be found further in the conference program. Co-Sponsored by the **Center for Economics and Neuroscience at University of Bonn** and **USC Dornsife College of Letters, Arts, and Sciences**

Sunday, September 27, 2015

ANNOUNCEMENTS **09:00 – 09:20**	**Camelia Kuhnen** Join us for the Early Career Award presentations, the Society Board Election Results and other Society information.
SESSION V **09:20 – 10:55**	***Finance and Aging*** Chair: **Paul Phillips**
9:20 – 9:40	***Adult age differences in the influence of financial skewness of choice and neural activity*** **Kendra Seaman** Kendra L. Seaman, Charlene C. Wu, Kiefer Katovich, Brian Knutson, Gregory R. Samanez-Larkin
9:45 – 10:05	***(Emotional) Reference Point Formation*** **Milica Mormann** M. Mormann, L. Nowlan
10:10 – 10:30	***A novel stock market task to investigate the neural underpinnings of financial decision making in rats*** **Annamarie Huttunen** A. Huttunen, E. M. Bowman
10:35 – 10:55	***Feedback-based learning in aging: Specific contributions of striatal and hippocampal systems*** **Nichole Lighthall** N.R. Lighthall, J.M. Pearson, S.A. Huettel, R. Cabeza
POSTER SPOTLIGHTS III **11:00 – 11:20**	Chair: **Tali Sharot**
	Risk taking as a complex phenotype: Identifying common and specific neural correlates of risk taking in multiple behavioural paradigms **Loreen Mamerow** Loreen Mamerow, Lilla Horvath, Renato Frey, Andreas Horn, Dirk Ostwald, Felix Blankenburg, Ralph Hertwig, Rui Mata
	Frequency specific modulation of reward processing and cognitive control **Zachary Yaple** Yaple, Zachary A, Awasthi, Bhuvanesh, Feurra, Matteo, Shestakova, Anna, Klucharev, Vasily
	Neural systems responding to degrees of social and non-social uncertainty as well as fairness **Emanuele De Luca** E. De Luca, J. Hillis, L. Muckli

	Social expectations reverse the effects of acetaminophen on economic decision-making **Ian Roberts** I.Roberts,I.Krajbich, B.Way
	Disentangling the effects of stress on neural components underlying the experience of empathy **Livia Tomova** Tomova, L., Majdandzik, J., Hummer, A., Windischberger, C., Lamm, C.
	Dopaminergic genes predict the cost of cognitive control and reliance on habit **Wouter Kool** W. Kool, M.M. Botvinick
POSTER SESSION III **11:25 – 13:25**	Please visit our poster presenters in the Porto, Faro and Algarve Rooms. A full list of poster presenters can be found later in the conference program. Sponsored in part by **The Faculty of Business and Economics** and **the Florey Institute of Neuroscience & Mental Health, The University of Melbourne**
12:00	Boxed Lunch
SESSION VI **13:30 – 15:05**	***Learning and Memory*** Chair: **Gregory Samanez-Larkin**
13:30 – 13:50	***Different Neural Mechanisms of Exploratory Behavior in Humans*** **Hans Melo** Hans Melo, Daniel J Mueller, William A Cunningham, Adam Anderson
13:55 – 14:15	***Reactivation of reward-related patterns from single experiences supports memory-based decision making*** **G Elliott Wimmer** G. Elliott Wimmer, Christian Büchel
14:20 – 14:40	***The Hippocampus as a Cognitive Map for Model-Based Planning*** **Oliver Vikbladh** O. Vikbladh, J. King, M. Meager, K. Blackmon, O. Devinsky, D. Shohamy, N. Burgess, N. Daw
14:45 – 15:05	***Single-Unit Representation of Value and Prediction Error in Human Amygdala During Reinforcement Learning*** **Juri Minxha** Juri Minxha, Simon Dunne, Adam N. Mamelak, Ralph Adolphs, John O'Doherty, Ueli Rutishauser

POSTER INDEX BY SESSION

About the Poster Sessions:

The Society for Neuroeconomics is pleased to present a wide range of current research through the poster sessions. The posters have been divided over three sessions, with each session on display for one day. The first number in the poster number signifies which session it will be presented in. Poster Session 1 (1) will be on display on Friday September 25, Poster Session 2 (2) will be on display on Saturday September 26, and Poster Session 3 (3) will be on display on Sunday September 27. Each poster is represented by a unique identifying code (ie.1.04). Posters will be displayed in numeric order during each session.

A complete list of poster titles and their presenting author and list of authors are listed on the following pages by poster session.

Poster Session 1

Friday September 25, 2015 – 15:50 – 18:00

AHMED, ALAA
Effort, reward, and vigor in decision-making and motor control
Authors: **Reza Shadmehr, Helen Huang, Alaa Ahmed**
Poster Number: 1.01

ALBRECHT, KONSTANZE
The perception of probabilities
Authors: **Konstanze Albrecht, Robert Böhm**
Poster Number: 1.02

ANGGRAINI, DIAN
To Locate My Rewards: Can Reinforcement Learning Help Me From Getting Lost?
Authors: **D. Anggraini, K. Wunderlich, S. Glasauer**
Poster Number: 1.03

ANTONY, MARKUS
The Impact of Food and Water Deprivation on Economic Decision Making
Authors: **Markus Antony, Armin Falk, Holger Gerhardt**
Poster Number: 1.04

BAULT, NADÈGE
Different attentional patterns for regret and disappointment: an eye-tracking study
Authors: **Nadège Bault, Pierre Wydoodt, Giorgio Coricelli**
Poster Number: 1.05

BAZLEY, WILLIAM
Color, Risk Preferences and Investment Decisions
Authors: **Milica Mormann, William Bazley**
Poster Number: 1.26

BLAIN, BASTIEN
Physical overtraining depletes cognitive control and biases intertemporal choice toward immediate reward
Authors: **B. Blain, C. Schmit, C. Hausswirth, Y. Le Meur, M. Pessiglione**
Poster Number: 1.06

CECCHINI, MARCO
Individual differences in disposition effect
Authors: **M. Cecchini, E. Bajo, P.M. Russo, M. Sobrero**
Poster Number: 1.07

CHUNG, HUI-KUAN
Neuroanatomical Correlates of Economic Rationality in Aging - Testing GARP
Authors: **Hui-Kuan Chung, Paul Glimcher, Agnieszka Tymula**
Poster Number: 1.08

COLOSIO, MARCO
Neural mechanisms of post-decisional spreading of alternatives: EEG study.
Authors: **Marco Colosio, Anna Spektor, Anna Shestakova, Vasily Klucharev**
Poster Number: 1.09

DI TELLA, CAROLINA
A systematic comparison of models of generosity
Authors: **Carolina Di Tella, Paul Glimcher, Wei Ji Ma**
Poster Number: 1.10

ENAX, LAURA
Oxytocin influences taste placebo effects
Authors: **Laura Enax, Hilke Plassmann, Sabrina Strang, Holger Gerhardt, Rene Hurlemann, Dirk Scheele, Nina Marsh, Bernd Weber**
Poster Number: 1.11

FELDMANHALL, ORIEL
Emotional arousal modulates choices under uncertainty
Authors: **Oriel FeldmanHalla, Paul Glimcherb, Augustus Bakera, Elizabeth A Phelps**
Poster Number: 1.12

GRUBB, MICHAEL
Neural representations of subjective value across the human lifespan
Authors: **M.A. Grubb, S. Rashid, P.W. Glimcher, I. Levy**
Poster Number: 1.13

HOGEVEEN, JEREMY
A valuation-based mechanism for increased apathy following ventromedial prefrontal damage
Authors: **Jeremy Hogeveen, Katherina K. Hauner, Frank Krueger, Jordan Grafman**
Poster Number: 1.14

IVO DA ROCHA LIMA FILHO, ROBERTO
An event-related analysis of the traders decision-making by using
Authors: **Roberto Ivo da R. L. Filho, Marcelo M. Taddeo, Paloma V. Uribe**
Poster Number: 1.15

KAZINKA, REBECCA
Ventromedial Patients Demonstrate Errors in Theory of Mind and Social Cognition
Authors: **R. Kazinka, P. McNally, T. Jiang, C. Bicchieri, J. W. Kable**
Poster Number: 1.16

KONOVA, ANNA
Do we need to treat risk? Attitudes toward risk and ambiguity in opioid addiction
Authors: **A. B. Konova, S. Lopez-Guzman, J. Rotrosen, S. Ross, P. W. Glimcher**
Poster Number: 1.17

KURNIANINGSIH, YOANNA
Dissociable decision making across prospective gains and losses: non-reflective risk preferences and differential choice strategies
Authors: **Yoanna A. Kurnianingsih, O'Dhaniel A. Mullette-Gillman**
Poster Number: 1.27

LARSEN, TOBIAS
Context can induce seeking behaviour in punishment conditions
Authors: **Tobias Larsen, Stefano Palminteri, Juan R. Vidal, Mehdi Khamassi, Mateus Joffily, Giorgio Coricelli**
Poster Number: 1.18

LEBRETON, MAEL
Inter-individual normalization of value representation in the human brain
Authors: **Mael Lebreton, Stefano Palminteri**
Poster Number: 1.19

LEE, SANGIL
Adaptive Learning Rates in a Continuously and Gradually Changing Environment
Authors: **Sangil Lee, Joshua I. Gold, Joseph W. Kable**
Poster Number: 1.20

LEMPERT, KAROLINA
Propranolol reduces reference-dependence in intertemporal choice
Authors: **Karolina M. Lempert, Sandra F. Lackovic, Russell H. Tobe, Paul W. Glimcher, Elizabeth A. Phelps**
Poster Number: 1.21

LOPEZ-GUZMAN, SILVIA
Treating Impulsivity: Temporal Discounting in Heroin Users undergoing Treatment
Authors: **Silvia Lopez-Guzman, Anna B. Konova, John Rotrosen, Stephen Ross, Paul W. Glimcher**
Poster Number: 1.22

LOPEZ-PERSEM, ALIZEE
Role of prior preference in shaping the neural format of subjective value
Authors: **Alizée Lopez-Persem, Philippe Domenech, Mathias Pessiglione**
Poster Number: 1.23

LU, TONG
From Web to Wardrobe: Joint Modeling of Eye Movements and Decisions
Authors: **T.J. Lu, J.W. Hutchinson**
Poster Number: 1.24

MARTINEZ-SAITO, MARIO
The effect of economic competition on the neural mechanisms of decision-making
Authors: **M. Martinez-Saito, A. Shestakova, V. Klucharev, B. Gutkin**
Poster Number: 1.25

MULLETTE-GILLMAN, O'DHANIEL
Value to utility transformations: the dorsomedial prefrontal cortex encodes subjective value modulation
Authors: **O'Dhaniel A. Mullette-Gillman, Yoanna A. Kurnianingsih**
Poster Number: 1.28

NADLER, AMOS
Single administration of testosterone impairs cognitive reflection in men
Authors: **Gideon Nave, Amos Nadler, Colin F Camerer**
Poster Number: 1.29

OLSON, ELIZABETH
Neural Correlates of Delay Discounting Alterations Associated With Trauma Exposure
Authors: **E. A. Olson, R. Fukunaga, I. M. Rosso**
Poster Number: 1.30

ONG, WEI SONG
Evaluating the neurobiology of strategic coordination in non-human primates
Authors: **Wei Song Ong, Michael Platt**
Poster Number: 1.31

PERUGINI, ALESSANDRA
Patients with Parkinson's Disease Fail to Use Memory to Guide Decisions Independent of Feedback
Authors: **Alessandra Perugini, Michele A. Basso**
Poster Number: 1.32

POGODA, LUCA
Preferences for foods can be predicted reliable across category and across time from different regions in prefrontal cortex: a longitudinal fMRI study
Authors: **Luca Pogoda, Bernd Weber**
Poster Number: 1.33

RAIO, CANDACE
Stress exposure decreases cooperative decision-making behavior
Authors: **C.M. Raio, O. FeldmanHall, M. Gaikwad, E.A. Phelps**
Poster Number: 1.34

RATALA, CATALINA
The Neural Mechanism of the Zero-Price Effect
Authors: **Cătălina E. Rățală, Maarten A.S. Boksem, Alan G. Sanfey, Ale Smidts**
Poster Number: 1.35

SAUTER, MARIAN
Interrupt the Impulse: Lateral prefrontal cortex function is necessary for optimal choice in the Prisoner's Dilemma
Authors: **Marian Sauter, Alexander Soutschek, Torsten Schubert**
Poster Number: 1.36

SOKOL-HESSNER, PETER
The dynamics of continuous self control
Authors: **P. Sokol-Hessner, N.D. Daw**
Poster Number: 1.37

TEE, JAMES
Evidence of Quantization in Intertemporal Decision Making
Authors: **James Tee, Joseph W. Kable, Laurence T. Maloney**
Poster Number: 1.38

TUSCHE, ANITA
Dissecting charitable giving: Empathy, mentalizing and reorienting of attention differentially predict generous donation decisions
Authors: **Anita Tusche, Tania Singer**
Poster Number: 1.39

VAN OPHEUSDEN, SEBASTIAAN
Characterizing human decision-making in combinatorial games
Authors: **Sebastiaan van Opheusden, Wei Ji Ma**
Poster Number: 1.40

VOSTROKNUTOV, ALEXANDER
Observational learning and its influence on the observer's learning rate
Authors: **A. Vostroknutov§, N. Bault, T. Larsen, L. Polonio, G. Coricelli**
Poster Number: 1.41

YUN, SUKHEE
Sense of choice during motivated encoding represented in reward processing region
Authors: **Suk-Hee Yun, Seung-Koo Lee, Sanghoon Han**
Poster Number: 1.42

ZIMMERMANN, JAN
Adaptive value coding: Temporal influences on choice mediated by divisive normalization in rhesus monkey
Authors: **Jan Zimmermann, Kenway Louie, Thomas LoFaro, Paul W. Glimcher**
Poster Number: 1.43

Poster Session 2

Saturday September 26, 2015 – 15:50 – 18:00

ASHTON, LYDIA
Hunger Games: Does Hunger Affect Time Preferences?
Author: **L. Ashton**
Poster Number: 2.01

BAKKOUR, AKRAM
Value-based decisions are influenced by memory retrieval
Authors: **Akram Bakkour, Michael N. Shadlen, Daphna Shohamy**
Poster Number: 2.02

BOLDT, ANNIKA
The evolution of uncertainty during the encoding of value
Authors: **A. Boldt, C. Blundell, B. De Martino**
Poster Number: 2.03

BROOKS, NICKOLAS
Neural Subjective Value Representations Depend on Decision Features: Time Delay, Physical Effort, and Probability Discounting
Authors: **Nickolas Brooks, Marissa A Gorlick, Todd A Hagen, Vanessa Holman, Linh Dang, Ming Hsu, David H Zald, Gregory R Samanez-Larkin**
Poster Number: 2.04

CHEN, YU-PING
Discriminating Honest and Dishonest Actions using Functional MRI
Authors: **Yu-Ping Chen, Lusha Zhu, Pearl Chiu, Brooks King-Casas, Ming Hsu**
Poster Number: 2.05

CHEN, WEI
Epiphany learning and pupil dilation in the 2-person beauty contest
Authors: **W. Chen, I. Krajbich**
Poster Number: 2.06

EISENBERG, IAN
Task-set selection in probabilistic environments: a model of task-set inference
Authors: **I.W. Eisenberg, R.A. Poldrack**
Poster Number: 2.07

ELBER, LOTEM
Alternative Interpretation to Action-Value Neurons in the Striatum
Authors: **Lotem Elber, Yanatan Loewenstein**
Poster Number: 2.08

ENAX, LAURA
The influence of nutrition labels on binary food choices: computational modeling approaches
Authors: **Laura Enax, Ian Krajbich, Bernd Weber**
Poster Number: 2.08

ENKAVI, AYSE ZEYNEP
Beyond Delay Discounting: Intertemporal Choice Between Non-Unitary Rewards
Authors: **A. Z. Enkavi, S.M. McClure**
Poster Number: 2.09

FALAHI, MOHSEN
The hysteresis of time-value curvature caused by directional gain/loss delay variation
Authors: **M. Falahi, S. Kamali, B. Azari, K. Preuschoff, Sh. Gharibzadeh**
Poster Number: 2.10

GERHARDT, HOLGER
Ego Depletion and Risk Attitudes: Is There a Causal Effect?
Authors: **Holger Gerhardt, Hannah Schildberg-Hörisch, Jana Willrodt**
Poster Number: 2.11

GLAZE, CHRISTOPHER
Why are decisions "noisy"? Evidence for stochastic discount rates in intertemporal choice.
Authors: **Christopher M. Glaze, Joseph W. Kable**
Poster Number: 2.12

GONG, XU
The effects of reciprocity on cooperative decision in gain and loss context and its relevant neural mechanisms
Authors: **Xu Gong, Yue-jia Luo**
Poster Number: 2.13

GRUESCHOW, MARCUS
Dynamic pupil dilations predict the precision of both perceptual and value-based choices
Authors: **Marcus Grueschow, Rafael Polania, Todd A. Hare, Christian C. Ruff**
Poster Number: 2.14

GWINN, RACHAEL
The spillover effects of attentional learning on value-based choice
Authors: **R. Gwinn, A. Leber, I. Krajbich**
Poster Number: 2.15

HALKO, MARJA-LIISA
Uncertainty, ambiguity and entrepreneurship
Authors: **K. Hytönen, T. Lahti, M-L. Halko**
Poster Number: 2.16

HARACZ, JOHN
Neural Networks Potentially Underlying Asset Trading: A Combined Herding/Rationality Choice Paradigm for Neuroimaging
Authors: **J.L. Haracz, C. Battista, T.J.H. Morgan, D. Marinazzo, M. Hofmann, M. Dhamala**
Poster Number: 2.17

HARRIS, LASANA
Might the brain disregard social information in economic contexts?
Authors: **L. T. Harris, V. K. Lee, R. Kranton**
Poster Number: 2.18

HSU, EUSTACE
Frontoparietal Activity During the Intertrial Interval Predicts Switching in Intertemporal Choice
Authors: **Eustace Hsu, John Monterosso**
Poster Number: 2.19

HYTONEN, KAISA
Haptic and Visual Descriptive Elements in Preference Formation
Authors: **K. Hytönen, J. Heinonen, S. Maunula, J. Suomala**
Poster Number: 2.20

JUNG, WI HOON
Neuroanatomical markers of individual differences in delay discounting: a voxel-based morphometry study
Authors: **Wi Hoon Jung, Rebecca Ashare, Mary Falcone, Caryn Lerman, Joseph W. Kable**
Poster Number: 2.21

KARMARKAR, UMA
Corticostriatal representation of information value during ambiguous decision-making
Authors: **Uma R. Karmarkar, Shengxuan Ye, Vaida Rimeikyte, Erik Kastman, Alexander Peysakhovich, Joshua W. Buckholtz**
Poster Number: 2.22

KRAJBICH, IAN
Attention and choice across domains
Authors: **S. Smith, I. Krajbich**
Poster Number: 2.23

LENOW, JENNIFER
Chronic and acute stress promote over-exploitation in foraging decisions
Authors: **K. Lenow, S.M. Constantino, N.D. Daw, E.A. Phelps**
Poster Number: 2.24

LIM, SEUNG-LARK
Psychological and Neurobiological Effects of Food Commercials on Children's Food Choices
Authors: **S.L. Lim, S.W. Pruitt, O.R. Ha, T.R. Smith, J.B.C. Cherry, J.M. Bruce, A.S. Bruce**
Poster Number: 2.25

LING, AIQING
Modulation of Judgments by Incidental Rewards: Physiological Foundation and Temporal Dynamics
Authors: **Aiqing Ling, Baba Shiv, Hilke Plassmann**
Poster Number: 2.26

MOISA, MARIUS
The precision of preference-based choices depends causally on directional oscillatory phase-coupling from prefrontal to parietal cortex
Authors: **Marius Moisa, Rafael Polania, Marcus Grueschow, Christian C. Ruff**
Poster Number: 2.27

MORMANN, MILICA
Testing Salience Theory of Risky Choice Using Eye-Tracking and Behavioral Data
Authors: **Milica Mormann, Cary Frydman**
Poster Number: 2.28

MOZUMDER, PALLAB
Status, Risk, and Catching Up
Author: **Pallab Mozumder**
Poster Number: 2.29

PARELMAN, JACOB
Risk preferences in a competitive social context
Authors: **J. M. Parelman, S. Hakimi, K. Fairley, J. M. Foster, R. M. Carter**
Poster Number: 2.30

PEHLIVANOVA, MARIETA
Neuroanatomical Correlates of Delay Discounting in Adolescents
Authors: **M. Pehlivanova, D.H. Wolf, R.E. Gur, R.C. Gur, C. Davatzikos, J.W. Kable, T.D. Satterthwaite**
Poster Number: 2.31

POLANIA, RAFAEL
Distinct prefrontal mechanisms underlying magnitude influences on the evidence for perceptual and value-based decisions
Authors: **Rafael Polania, Marcus Grueschow, Ian Krajbich, Christian C. Ruff**
Poster Number: 2.32

RAVAIOLI, SILVIO
A dynamic threshold model of optimal stopping
Authors: **S. Ravaioli, L. Polonio, M. Sodini, G. Coricelli**
Poster Number: 2.33

REECK, CRYSTAL
Neural Mechanisms Promoting Selflessness in Potential Conflicts of Interest
Authors: **Crystal Reeck, Nina Mazar, Dan Ariely, Rita Ludwig, Malia F. Mason**
Poster Number: 2.34

SEINSTRA, MAAYKE
Stimulating impulsivity: does Subthalamic Nucleus Deep Brain Stimulation affect Intertemporal decision making in Parkinson patients?
Authors: **M. Seinstra, L. Wojtecki, L. Storzer, A. Schnitzler, T. Kalenscher**
Poster Number: 2.35

SELBING, IDA
Verbal Descriptions of Others' Ability Corrupt Avoidance Learning from Observing their Behavior
Authors: **I. Selbing, A. Olsson**
Poster Number: 2.36

SMITH, DAVID
The Striatum Multiplexes Distinct Reward Signals
Authors: **David V. Smith, Kainan S. Wang, Mauricio R. Delgado**
Poster Number: 2.37

STEIMKE, ROSA
Decomposing Self-Control Using a Novel Eyetracking Task: Individual Differences in Goal Pursuit Despite Interfering Aversion, Temptation, and Distraction
Authors: **Rosa Steimke, Christine Stelzel, Robert Gaschler, Marcus Rothkirch, Vera U. Ludwig, Lena Paschke, Ima Trempler, Norbert Kathmann, Thomas Goschke, Henrik Walter**
Poster Number: 2.38

UGAZIO, GIUSEPPE
Decreasing inequality aversion with non-invasive brain stimulation
Authors: **Giuseppe Ugazio, Christopher Burke, Christian C. Ruff, Philippe N. Tobler**
Poster Number: 2.39

VOGT, BODO
Testing the causal influence of vasopressin on cooperation and altruistic punishment: a randomized intranasal administration study
Authors: **Claudia Brunnlieb, Gidi Nave, Stephan Schosser, Colin F. Camerer, Bodo Vogt**
Poster Number: 2.40

WEISSENGRUBER, SEBASTIAN
Model Based vs. Model Free Learning: Who's Controlling the Controller?
Authors: **Sebastian Weissengruber, Sang Wan Lee, John P. O'Doherty, Christian C. Ruff**
Poster Number: 2.41

XIE, DIANA
Hierarchical hidden Markov modeling of real time changes in strategic behavior in a game theoretic context
Authors: **Diana L. Xie1*, Jeffrey M. Beck, Jean-Francois Gariepy, Michael L. Platt**
Poster Number: 2.42

YE, KAREN
Market Experience Attenuates the Endowment Effect through Modulation of Anterior Insula: A Training Study
Authors: **K.J. Ye, K. Asai, L.C.P. Tong, S. Ertac, J.A. List, H.C. Nusbaum, A. Hortaçsu**
Poster Number: 2.43

YU, LINDA
Timing of value representation in ventromedial prefrontal cortex in a complex auction task
Authors: **L. Q. Yu, N. Cooper, G. Zauberman, B. K. Kim, J. W. Kable**
Poster Number: 2.44

Poster Session 3

Sunday September 27, 2015 – 11:25 – 13:25

BUTCHER, PETER
Reach trajectories as another index of preferences in dietary choice
Authors: **P.A. Butcher, A. Shenhav, M.A. Straccia, J.D. Cohen, M.M. Botvinick**
Poster Number: 3.01

DE LUCA, EMANUELE
Neural systems responding to degrees of social and non-social uncertainty as well as fairness
Authors: **E. De Luca, E. Fouragnan, J. Hillis, L. Muckli**
Poster Number: 3.02

FOERDE, KARIN
Neural Mechanisms Supporting Persistent Maladaptive Food Choices
Authors: **Karin Foerde, Joanna Steinglass, Daphna Shohamy, B. Timothy Walsh**
Poster Number: 3.03

FREESTONE, DAVID
Ventral tegmental dopaminergic stimulation causes preference reversals
Authors: **D.M. Freestone, L. Grattan, R.B. Rutledge, K. Louie, P.W. Glimcher**
Poster Number: 3.04

HAMPTON, WILLIAM
Wired For Now? Orbitofrontal Cortex-Ventral Striatum Structural Connectivity Predicts Individual Differences in Delay Discounting
Authors: **William Hampton, Vinod Venkatraman, Ingrid Olson**
Poster Number: 3.05

HANSON, ERICA
Fos expression after exposure to an effort discounting procedure
Authors: **E. E. Hanson, S. H. Mitchell**
Poster Number: 3.06

HÄUSLER, ALEXANDER
Predicting real life stock purchase via individual differences in demographics, personality, risk preferences, and neural processing
Authors: **A.N. Häusler, S. Rudorf, A.J. Forstner, C.M. Kuhnen, M.M. Nöthen, B. Weber**
Poster Number: 3.07

HOLLAND, CATHERINE
Age Differences in Discounting of Time, Probability, and Effort Across Monetary, Social, and Health Domains
Authors: **Catherine A. C. Holland, Marissa A. Gorlick, Brad Ward, Ming Hsu, David H. Zald, Gregory R. Samanez-Larkin**
Poster Number: 3.08

HUNTER, LINDSAY
Model-based learning predicts increased patience in intertemporal choice
Authors: **L. E. Hunter, T. C. Shi, Y. Soufian, J. H. Decker, C. A. Hartley**
Poster Number: 3.09

KHAW, MEL WIN
Value aftereffects: evidence for dynamic adaptation in the valuation process of human subjects
Authors: **Mel W. Khaw, Paul W. Glimcher, Kenway Louie**
Poster Number: 3.10

KOBAYASHI, KENJI
Neural Representation of Value of Information
Authors: **Kenji Kobayashi, Ming Hsu**
Poster Number: 3.11

KONOVALOV, ARKADY
Gaze data reveal different choice processes underlying model-based and model-free reinforcement learning
Authors: **A. Konovalov, I. Krajbich**
Poster Number: 3.12

KOOL, WOUTER
Dopaminergic genes predict the cost of cognitive control and reliance on habit
Authors: **W. Kool, M.M. Botvinick**
Poster Number: 3.13

KUNG, CHUN-CHIA
The neural substrate of maternal love in shopping: comparing general linear model and searchlight mapping
Authors: C**hun-Chia Kung, Ding-Ruey Yeh , Ming-Hung Weng**
Poster Number: 3.14

LANDRY, PETER
Divisive Normalization Yields Attraction and Compromise Effects
Authors: **Peter Landry, Ryan Webb**
Poster Number: 3.15

LEVY, DINO
Visual spatial frequencies affect value-based choices
Authors: **Dino J Levy, Tal Sela**
Poster Number: 3.16

MADLON-KAY, SETH
Investigating the role of SHANK3 in social decision-making in free-ranging rhesus macaques
Authors: **Seth Madlon-Kay, Alex Bay, Rebecca Passman, Lauren Brent, Karli Watson, Pate Skene, Julie Horvath, Yong-Hui Jiang, Michael Platt**
Poster Number: 3.17

MAIER, SILVIA
Linking differences in baseline physiology to self-control performance
Authors: **Silvia U. Maier, Todd A. Hare**
Poster Number: 3.18

MAMEROW, LOREEN
Risk taking as a complex phenotype: Identifying common and specific neural correlates of risk taking in multiple behavioural paradigms
Authors: **Loreen Mamerow, Lilla Horvath, Renato Frey, Andreas Horn, Dirk Ostwald, Felix Blankenburg, Ralph Hertwig, Rui Mata**
Poster Number: 3.19

MOLTER, FELIX
The role of eye movements in contextual risky choice
Authors: **Felix Molter, Hauke R. Heekeren, Scott A. Huettel, Peter N. C. Mohr**
Poster Number: 3.20

O'BRIEN, MEGAN
Loss aversion in effort-based decision making
Authors: **M.K. O'Brien,A.A. Ahmed**
Poster Number: 3.21

PANIDI, KSENIA
Exploring the role of DLPFC in the interconnection between risk and time preferences using transcranial magnetic stimulation
Authors: **Ksenia Panidi, Vasily Klucharev, Anna Shestakova, Matteo Feurra, Dmitry Ivanov**
Poster Number: 3.22

RAJA BEHARELLE, ANJALI
Reducing left dlPFC excitability with tDCS impairs dietary self-control
Authors: **Anjali Raja Beharelle, Silvia Maier, Christian Ruff, Todd Hare**
Poster Number: 3.23

ROBERTS, IAN
Social expectations reverse the effects of acetaminophen on economic decision-making
Authors: **I.Roberts,I.Krajbich, B.Way**
Poster Number: 3.24

REYNA, VALERIE (PRESENTED BY MICHAEL JOHN MCCORMICK)
Neural Correlates of Verbatim and Gist Processing of Risky Choices in Adolescents: A Fuzzy-Tracy Theory Analysis
Authors: **V. F. Reyna, M. McCormick, A. E. Evans, C. F. Chick, R. B. Weldon, R. A. Setton**
Poster Number: 3.25

SAEZ, IGNACIO
Cortical electrophysiological activity underlying decision-making under risk
Authors: **Ignacio Saez, Edward Chang, Jack Lin, Josef Parvizi, Robert T.Knight, Ming Hsu**
Poster Number: 3.26

SAMANEZ-LARKIN, GREGORY
Regulation of Desires in Everyday Life Partially Mediates the Relation Between Dopamine and BMI Across the Human Life Span
Authors: **Daniel Weiner, Linh Dang, Jaime Castrellon, Scott Perkins, Kruti Vekaria, David H Zald, Gregory R Samanez-Larkin**
Poster Number: 3.27

SHABAT SIMON, MAYTAL
State-dependent valuation and choice: behavioral and physiological interactions between internal state and decision making
Authors: **Maytal Shabat Simon, Anastasia Shuster, Tal Sela, Dotan Persitz, Dino J Levy1**
Poster Number: 3.28

SHENHAV, AMITAI
Dorsal anterior cingulate and ventromedial prefrontal cortex have inverse roles in both foraging and economic choice
Authors: **A. Shenhav, M.A. Straccia, J.D. Cohen, M.M. Botvinick**
Poster Number: 3.29

SHUSTER, ANASTASIA
The Neural Representation of Money and Prices
Authors: **Anastasia Shuster, Ryan Webb, Dino Levy, Paul Glimcher**
Poster Number: 3.30

STOJIC, HRVOJE
Human behavior in contextual multi-armed bandit problem
Authors: **H. Stojic, P.P. Analytis, M. Speekenbrink**
Poster Number: 3.31

TOMOVA, LIVIA
Disentangling the effects of stress on neural components underlying the experience of empathy
Authors: **Tomova, L., Majdandzik, J., Hummer, A., Windischberger, C., Lamm, C.**
Poster Number: 3.32

VAIDYA, AVINASH
Choice is bought by judgment of the eye: Necessary prefrontal contributions to value updating during decision-making
Authors: **A.R. Vaidya, L.K. Fellows**
Poster Number: 3.33

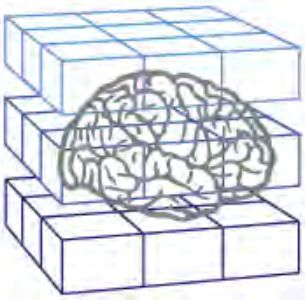
WEBB, RYAN
Dynamic Constraints on the Distribution of Stochastic Choice
Author: **Ryan Webb**
Poster Number: 3.34

YAPLE, ZACHARY
Frequency-specific modulation of risk, certainty and cognitive control
Authors: **Yaple, Zachary A, Awasthi, Bhuvanesh, Feurra, Matteo, Shestakova, Anna, Klucharev, Vasily**
Poster Number: 3.35

YEE, DEBBIE
Monetary and Liquid Incentives Combine to Modulate Cognitive Task Performance
Authors: **D. Yee, T.S. Braver**
Poster Number: 3.36

YEN, NAI-SHING
Neural Correlates of the Escalation of Commitment: An fMRI Study
Authors: **Yuwen Li, Ting-Peng Liang, Nai-Shin Yen, Shen-Mou Hsu, Wan-Ting Tsai**
Poster Number: 3.37

ZHU, LUSHA
The value of honesty: Neural evidence for lie-averse preferences
Authors: **Lusha Zhu, John Wang, Sheryl Ball, Ming Hsu, Pearl Chiu, Brooks King-Casas**
Poster Number: 3.38



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Session I
Consumer Behavior and organizations

Influencing cognitive control: the effect of social pressure vs. monetary incentives

Mina Godec[1], Sergeja Slapnicar[1], Frank Hartmann[2], Anka Slana[3] & Grega Repovs[3]

[1]Faculty of Economics, University of Ljubljana, Slovenia
[2]Rotterdam School of Management, Erasmus University, the Netherlands
[3]Mind & Brain Lab, Faculty of Arts, University of Ljubljana, Slovenia

Correspondence: sergeja.slapnicar@ef.uni-lj.si

Objective:
Organisations enhance performance of agents through various control mechanisms, among which monetary incentives and social pressure are the most notable. Positive effect on performance is thought to occur because of increased cognitive effort and greater 'rationality' of decision making that such mechanisms induce in human agents. To enhance our understanding of what makes control mechanisms effective requires an examination of how they affect fundamental drivers of cognition. The aim of our research is to compare the effects of monetary incentives vs. social pressure on cognitive system that underlies human ability to think analytically, plan and execute complex tasks – i.e. cognitive control.

Methods: 30 financial managers took part in an fMRI recording while performing Eriksen Flanker Task in baseline - and two manipulated conditions: monetary incentive and social pressure. In the monetary incentive condition subjects were told that the speed and accuracy of their responses will determine the amount of monetary contribution to charity, but also subtractions from the money earned in case of errors. In social pressure condition subjects were told that the results and their ranking will be published. Performance was measured in terms of reaction times and accuracy rates.

Results: Both, monetary incentive and social pressure significantly improved reaction times at no significant loss of accuracy. Interestingly, we find no significant differences in performance between both conditions. The analysis of sustained brain activity comparing manipulated conditions vs. baseline revealed an increase in the extent and intensity of activation in regions of attentional and cognitive control, as well as subcortical structures related to gating of sensory information. Investigation of behavioural performance correlations suggested separable roles of identified regions, contributing to overall speed of performance (e.g. midcingulate cortex) or reduced interference effects (e.g. thalamus). Comparison of sustained activity between the monetary incentive and social pressure revealed no significant differences, however, further analysis of trial-by-trial transient brain responses during conditions identified significant effect of control mechanism on response in orbitofrontal cortex.

Conclusions: Our analysis suggests that social pressure represents a similarly strong impetus for performance improvement as monetary incentive, although achieved through different pattern of brain systems activation.

Acknowledgements:
This study was funded by CIMA.

Multivariate encoding of neural responses to movie-trailers is associated with individual evaluation and predictive of commercial success

Hang-yee Chan[1*], Vincent Schoots[1], Alan Sanfey[2,3], Ale Smidts[1], and Maarten Boksem[1]

[1]Rotterdam School of Management, Erasmus University; [2]Donders Institute for Brain, Cognition & Behaviour, Radboud University Nijmegen; [3]Behavioural Science Institute, Radboud University Nijmegen.

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Objective: Understanding how consumers respond to products is crucial for marketers. Previous studies point to caudate nucleus, ventral striatum and ventromedial prefrontal cortex as sites of implicit valuation, and find activities in those areas to be predictive of individual product evaluation and population-wide commercial success.

Despite these early successes, analyzing consumer neural responses to products poses methodological challenges. First, conventional single-site activation analysis in most previous studies potentially misses more distributed neural activities such as emotions. Second, handling neural responses to complex, dynamic stimuli (such as video and music) requires data reduction. While the common practice is to calculate voxel averages or treat them as event blocks, rich temporal information is lost in the process.

Methods: We propose a multivariate approach to encode dynamic neural responses during movie-trailer watching. Twenty-eight participants viewed cinematic trailers of 18 movies (each about 2 minutes long) while undergoing fMRI scanning. We collected individual evaluations (valence, arousal, willingness to pay and choice), critics' evaluations (Rotten Tomatoes scores) and commercial success (US box office). In addition, participants passively viewed a series of lotteries (value localizer task) and a series of valence and arousal IAPS pictures (emotion localizer task).

With support vector machine (SVM) searchlight algorithms, areas most predictive of emotion- and value-related stimuli in the localizer tasks were located. Data of all subjects were then transformed into a common space through hyperalignment. The pooled localizer data were used to train two emotion (valence and arousal) SVM classifiers and two value (anticipated and actual gain/loss) classifiers. With these, neural responses during movie-trailer watching were encoded by classifying each brain volume with two emotion and two value attributes.

Results: Encoded neural responses uniquely identified movie trailers across subjects in cross-validated SVM classification (accuracy: 84%; chance: 6%). They also significantly corresponded with individual evaluations. Importantly, encoded neural responses significantly predicted critics' ratings and commercial success (cross-validated R^2 = .13 and .24, respectively).

Conclusions: We show that multivariate encoding of neural responses can be useful in analyzing complex, dynamic stimuli, such as movies and advertisements. With this approach, marketers can inspect moment-by-moment neural responses in a meaningful way.

Neural prediction of crowdfunding decisions

Alexander Genevsky[1*], Carolyn Yoon[2], and Brian Knutson[1]

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[2] Ross School of Business, University of Michigan

[*]Correspondence at: genevsky@stanford.edu, knutson@psych.stanford.edu

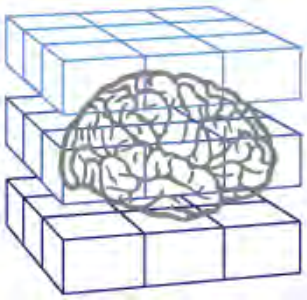
Objective: Crowdfunding refers to the practice of using small financial contributions from a large group of investors in order to raise capital to fund products or ventures. The popularity of crowdfunding on the internet has grown exponentially in recent years, and in 2014 raised for over $10 billion. Crowdfunding websites offer a unique opportunity for individuals to engage with products as both financial supporters and consumers. This combination of motivations – self-interested and other-focused – may explain in part the great appeal of these websites. However, despite its growing popularity and economic significance, the neural and psychological mechanisms responsible for individual decisions to fund projects have not been explored.

Methods: Here we report a neuroscience perspective on crowdfunding decision-making. In order to assess the ability of neural activity to predict funding behavior we had participants make incentive compatible decisions regarding 36 actual crowdfunding projects while being scanned in the fMRI magnet. We used neural data collected during the task to predict both individual decisions to fund and the real-world funding outcomes of these projects on the internet.

Results: Neural analysis contrasting whole-brain activity in trials in which participants decided to fund versus trials in which they did not, indicated significant differences in a defined subset of regions associated with positive affect (i.e., bilateral nucleus accumbens and caudate) and value integration (i.e, medial prefrontal cortex). Greater activation in these areas while viewing the projects was associated with eventual decision to fund. This activity occurred before the decision phase of the trial, and is thus temporally distinct from activity associated with the act of indicating a choice. Further, only nucleus accumbens activity scaled to predict market-level funding outcomes on the internet.

Conclusions: In this study, we identified specific neural circuits whose activity predicted individuals' choices to contribute to crowdfunding projects. These neural regions have been previously associated with positive affect, suggesting that projects that effectively activate psychological mechanisms of positively aroused affect are more likely to receive funding. These findings highlight the potential for affective neuroscience to predict funding decisions in a new domain of consumer decision-making with significant economic consequences, to hone theoretical accounts about which neuropsychological mechanisms drive crowdfunding decisions, and eventually, to improve the practice of constructing effective project appeals.

Acknowledgements:
This study was funded by the Stanford NeuroChoice Initiative.



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Poster Session 1
By Poster Number

Effort, reward, and vigor in decision-making and motor control

Reza Shadmehr[1], Helen Huang[2], Alaa Ahmed[2*]

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Objective: Decisions depend on the reward at stake and the effort required. However, these same variables influence the vigor of the ensuing movement, suggesting that factors that affect evaluation of action also influence its performance. Here, we consider a mathematical framework that has the potential to unify components of decision-making with motor control. In this framework, each action has a utility that combines the reward at stake with its effort requirements, both discounted as a hyperbolic function of time. The critical assumption of our model is to represent effort via the metabolic energy expended to produce the movement.

Methods and Results: We propose that the brain objectively represents effort via the expected metabolic cost of the action. We show that this energetic representation provides a parameterization of effort as a function of movement duration, mass, distance, and force. We confirm this experimentally by measuring metabolic cost in reaching movements via expired gas analysis. The resulting representation of effort makes predictions regarding what animals should do when faced with the option of choosing between movements of different duration, mass, distance, and force. To test the predictions, we consider the following data sets:

1. Subjects not only prefer the more rewarding stimulus, but also move faster toward it.
2. Subjects prefer to reach to stimuli that require transport of a smaller mass, but do so with higher vigor than when forced to make the same amplitude movement with a larger mass.
3. Subjects are willing to perform actions that require greater effort, but only in exchange for greater reward. However, they move with less vigor when forced to perform the less preferable action.
4. Increasing the duration that subjects have to wait before making a movement reduces the vigor of the ensuing movement.
5. In a task with objective measures of reward and effort via their caloric values, subjects choose actions consistent with a utility in which reward and effort are discounted by the duration of the action.
6. As the duration of generating an isometric force increases, the utility of effort does not continue to increase, but rather reaches a plateau.
7. Natural walking speed, and well as the speed of performing other actions, varies with the reward landscape of the city in which people live.

Conclusions: Our main result is to show that a single mathematical formulation of action, based on an objective measure of effort, can provide insights into both the decision that animals make, as well as the vigor of the movements that follow. This framework accounts for choices that birds make in walking vs. flying, choices that people make in reaching and force production, and the curious fact that pedestrians walk faster in certain cities. We suggest that in decision-making and motor control, the brain may objectively represent effort via the actual metabolic cost of the planned movement, discounted as a function of time.

The perception of probabilities

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Objective: In our world, many things are normally distributed. However, other distributions exist. For example, a series of die rolls is equally distributed. I.e., in each roll, rolling a 6 is as likely as rolling any other number on the die. Most people are aware of this fact. Yet, they nevertheless show a systematic bias in judging the probability of the occurrence of such numbers by assuming that a 1 or a 6 are less likely to occur than a 3 or 4. We hypothesize that this bias arises because people implicitly assume a normal instead of an equal distribution when judging the probability of rolling a certain number.

Methods: 265 adult subjects participated in the study so far and more data is collected currently. Each subject was told to privately roll a die twice, their first roll yielding the decade and the second roll yielding the unit position of a two-digit number. Subjects then reported the two-digit number to the experimenter, knowing that reporting a two digit-number larger than 46 (i.e., 51 to 66) would enter them in a lottery, in which they could win 50 euros. If they reported a number smaller than 51 (i.e., 11 to 46), they would not be entered into the lottery and thus had no chance to win. We used two digits in order to make a potential normal distribution of reported numbers more detectable.

Results: Given that reporting a number below 51 means that subjects are not eligible to enter the lottery, it can be assumed that most subjects would only report such a number if it was truthfully rolled. Thus, the distribution of reported numbers below 51 should be an equal one, given a sufficient number of subjects. As expected, we found that reported numbers below 51 are close to an equal distribution. Given that there is an incentive to lie and that a lie is not detectable, we expect a sufficient number of subjects who rolled a number smaller than 51 to report higher numbers. As expected, reported numbers from 51 to 56 significantly deviate from an equal distribution, and are distributed closer to a normal distribution. In order to consolidate these results, we currently collect more data.

Conclusions: These results suggest that one bias in the perception of probability might be due to implicitly assuming that die rolls are distributed along a normal distribution even though the real distribution is an equal one. In ongoing research we investigate how implicit this assumption really is, whether the assumption of others' beliefs play a role (i.e. whether people report numbers according to what they think others will consider as more likely to occur and thus as less likely to be a lie) and how such numbers are generated by the human mind.

To Locate My Rewards: Can Reinforcement Learning Help Me From Getting Lost?

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Objective:

Studies on decision making report that humans employ either a model-free repetition of successful behavior or a more demanding model-based approach to learn which decisions to make to maximize reward or avoid lost. A similar dual strategy approach, generally termed as route-based versus map-based strategy, exists when we navigate in novel environment.

In this study, we aim to: 1) develop a behavioral paradigm that encourages subjects to use either a route-based or map-based strategy in specific trials of spatial navigation; 2) investigate the relationship of the neural process underlying model-free vs. model-based decision making and route vs. map-based navigation; 3) examine brain areas pertaining to computationally relevant signals during the spatial navigation.

Methods:

Twenty three healthy, right handed female between 21 to 29 years of age performed spatial decision task while undergoing functional magnetic resonance imaging (fMRI). The task consisted of navigation within a 3D virtual reality 5 x 5 grid world. In the first session, subjects had to repeatedly find rewards located in fixed designated rooms promoting a route-based strategy. In further sessions, we encouraged map-based planning of new routes by asking subjects to find particular rewards. We characterized subjects' learning behavior by fitting several reinforcement learning (RL) type algorithm (model-free, model-based, and hybrid models) to explain subjects' trial-by-trial choices.

Results:

Subjects were able to utilize the provided cues to navigate and find optimal paths to reach rewards. The RL models provided a good fit to subjects' behavior during spatial navigation. Importantly, we were able to distinguish between route-based and map-based navigation using weighted combination of model-free and model-based algorithm. Ongoing preliminary fMRI analysis suggests that brain regions relevant for decision making are also involved in the computations required during spatial navigation.

Conclusion:

Our results suggest that subjects' choice behavior in a spatial decision task can be explained by an RL model. Currently ongoing analyses linking the RL parameters to BOLD activity will allow an in-depth investigation of the neural correlates of the computational process that the brain carries out during spatial navigation.

The Impact of Food and Water Deprivation on Economic Decision Making

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Objective: The availability of food and water, respectively the scarcity thereof, varies substantially across regions and social environments. In developed countries, hunger and thirst are generally less severe than in the third world, but they still fluctuate in the course of a day. Research related to the idea of "ego depletion" has found evidence that a low level of blood glucose—which is a consequence of short-term food deprivation—induces changes in behavior in various domains. In particular, we hypothesized that short-term food and water deprivation would lead to a lower willingness to cooperate for obtaining a food reward, to a decreased willingness to take risks for obtaining water, and to reduced performance in neuropsychological tests.

Methods: We conducted a lab experiment lasting approx. 10 hours. Sessions started at 9:00 a.m. During the experiment, subjects in the treatment group (n = 100) were deprived of both food and water until at least 4:30 p.m.; subjects in the control group (n = 100) received a snack and a beverage at lunchtime. In the early afternoon, when the expected metabolic states of the two groups were most divergent, subjects faced a series of decision tasks—including a prisoner's dilemma over pizza slices, lottery choices over amounts of water, as well as a dictator game and a trust game over money. We repeatedly measured blood glucose levels and other biometric markers, let subjects perform neuropsychological tests (e.g., the Stroop test), and asked them about their mood and sensations of hunger and thirst throughout the experiment.

Results: Deprived subjects had significantly lower blood glucose levels and reported significantly greater hunger, thirst, and other indicators of discomfort (all $p < 0.001$). Contrary to our hypotheses, we observe only small, mostly statistically insignificant, differences between the decisions of deprived and non-deprived subjects; the same applies to subjects' performance in the neuropsychological tests. In particular, cooperation rates in the prisoner's dilemma over food (76% vs. 80%, $p = 0.6090$) and risk attitudes over water ($p = 0.5035$) did not differ significantly.

Conclusion: We find that several hours of food and water deprivation had a sizeable effect on our subjects' physiological and emotional state. However, our manipulation did not affect behavior in a statistically significant way. This suggests that short-term fasting and the associated decrease in blood glucose can be mainly compensated, such that their influence on behavior is limited. Hence, the alleged impact of blood glucose on decision making—as suggested, e.g., in the idea of "ego depletion"—may have to be reconsidered.

Different attentional patterns for regret and disappointment: an eye-tracking study

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Objective: The unfavorable comparison between the obtained and the expected outcome of our choices may elicit disappointment. When the comparison is made with the outcome of alternative actions, emotions like regret can serve as a learning signal. Previous work showed that both anticipated disappointment and regret influence decisions. In addition, experienced regret is associated with higher emotional responses than disappointment. Yet it is not clear whether this amplification is due to additive effects of disappointment and regret when the outcomes of alternative actions are available, or whether it reflects the learning feature of regret signals.

Methods: In this perspective, we used eye-tracking to measure the visual pattern of information acquisition in a probabilistic lottery task. In the partial feedback condition, only the outcome of the chosen lottery was revealed, while in the complete feedback condition participants could compare their outcome with that of the non-chosen lottery, giving them the opportunity to experience regret.

Results: During the decision phase, visual patterns of information acquisition were consistent with the assessment of anticipated regret, in addition to a clear assessment of lotteries' expected values. During the feedback phase, subjective ratings and eye-tracking results confirmed that participants compared their outcome with the outcome of the non-chosen lottery in the complete feedback condition, particularly after a loss, and ignored the non-realized outcome of the chosen option. Moreover, participants who made more visual saccades consistent with counterfactual comparisons during the feedback period anticipated regret more in their decisions.

Conclusions: Our data show that the experience of regret affected the way in which participants acquired visual information in future choices; in particular they increased the amount of inter-lottery saccades in late trials. These findings provide evidence for a dynamic interplay between emotions and attention in decision-making. Thus, a specific pattern of attention characterizes the experience of regret during unfavorable outcomes, and then in turn experienced regret affects the pattern of visual information acquisition in subsequent, regret-avoiding choices. The current study thus provides evidence for a regret-related attentional pattern in decision-making, consistent with the proposed adaptive function of regret.

Acknowledgements:
Financial support from the LABEX CORTEX (ANR-11-LABX-0042) and the European Research Council (ERC-2013-CoG) is gratefully acknowledged.

Physical overtraining depletes cognitive control and biases intertemporal choice toward immediate reward

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Objective: A recent hypothesis about the neural mechanisms underlying intertemporal choice (Hare et al., 2014) suggests that option values are encoded in a ventral prefrontal system, which is regulated by a dorsal prefrontal system when self-control is necessary to resist the attraction of immediate rewards. Accordingly, inhibition of the dorsal prefrontal cortex using TMS was found to bias choices toward immediate rewards (Figner et al., 2010). In a previous study, we showed that a more ecological situation (prolonged cognitive effort over seven hours as in a workday) can also induce a bias toward more impulsive inter-temporal choices. This behavioral effect was linked to decreased activity in the Middle Frontal Gyrus (MFG), a region that was implicated in performing both hard cognitive task and inter-temporal choice. Here, we test whether an overload of sport exercise resulting in an overreaching state (defined as impaired physical performance associated with high perceived fatigue) could also increase impulsivity in inter-temporal choice and decrease related MFG activity.

Methods: In total, 27 healthy triathletes participated in the study. They were divided into two groups: a control group (N = 18) which followed its habitual training program and the overtrained group (N = 9) which was submitted to a 40% overload during a 3-week period. FMRI data were acquired in both groups, while they were performing cognitive control tasks, intermingled with inter-temporal choices.

Results: As expected, behavioral data showed an increase in impulsive choice (preference for immediate rewards) for the overtrained group compared to the control group. At the neural level, the overtrained group exhibited a decreased activity in the MFG region involved in inter-temporal choice, relative to the control group. Moreover, we observed a significant brain-behavior correlation across subjects, such that the lower the activity in MFG, the higher the impulsivity in choice.

Conclusion: These findings are consistent with the theory that cognitive control resources might be depleted after intensive use (here, three weeks of overloaded physical training), releasing an impulsive tendency to go for immediate gratification. This implies that intense physical training mobilizes cognitive control resources, possibly for inhibiting or overcoming aversive signals linked to pain and fatigue.

References:
Figner B, et al. (2010) Lateral prefrontal cortex and self-control in intertemporal choice. *Nature neuroscience* 13(5):538–539.
Hare TA, Hakimi S, Rangel A (2014) Activity in dlPFC and its effective connectivity to vmPFC are associated with temporal discounting. *Frontiers in neuroscience* 8. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3957025/ [Accessed June 1, 2015].

Acknowledgements: This study was funded by the French Anti-Doping Agency (AFLD, Paris). BB was supported by a fellowship from the Délégation Générale de l'Armement.

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Individual differences in disposition effect

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Objective: We investigate the role of personality traits in explaining the tendency to sell stocks at gain rather than at loss. Building on the findings of a considerable hidden cross-section variation in the understanding of the disposition behaviour, our main goal is to monitor data features that are no visible at an aggregated level of analysis.

Methods: To detect interindividual differences in the investment heuristics we use experimental analysis in a sample of 359 students from Economics and Engineering Faculties both at University of Bologna (Italy) and at University of Wuhan (China). Using NEO IP-R five-factor personality inventory as well as trading simulations, we construct measures of personality traits for each subject, and we correlate these measures with trading records. We analyzed our data using Tobit regression model.

Results: At odds to the folk usual picture of successful investors who trade aggressively and impulsively, we find that personality traits, like extraversion and conscientiousness, are respectively positive and negative related with the biased financial behaviour. In particular, in line with the neuro-psychological literature that demonstrates a link between extraversion and high sensitivity to reward (Carven and White, 1994; Smillie, 2013), we report that extroverts prefer short-term capital gains instead of delayed profits. Moreover, low impulsive investors base their trading activities on a non-immediate aim-achievement (Holt et al., 2003) that lead them to follow long-term strategies for the main goal of higher return. Finally, the fact that in our experiment open mind investors close negative positions faster than positive reinforces the theories (McCrae & Costa 1992; Lauriola & Levin, 2001; LePine, 2003) that suggest the trait to be actively influenced by new information in reducing harm-avoidance behaviour, especially in the gain domain, and less locked into pre-mechanism processes that lead the subject to repeat the same action over time.

Conclusions: These findings seem to suggest a specific "personality profile" less affected by disposition effect that is coherent with the previous experimental studies on emotional responses and successful trading (Lo et al., 2005).
An implementation of the models that describe anomalies in asset pricing as naïve diversification and excessive trading is suggested. Providing a clear picture of each investor as human being might also motivate brokerage firms to make subjects aware of such bias and help them to obtain better performances.

Acknowledgements:
I would like to thank all the seminars participants at the Ross Business School, University of Michigan, where a preliminary version of this study has been presented on May 2015.

Neuroanatomical Correlates of Economic Rationality in Aging - Testing GARP

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Objective: The population of people above 65 is growing and work studying their decision making is of increasing significance. We previously (Tymula, et al., 2013) found that highly functional elders are likely to make fundamental choice errors in economic situations (more likely to violate "first-order stochastic dominance") compared with all younger subjects. However, there is no biomarker for this "irrational performance" at the individual level, and insufficient evidence on the effects of neuroanatomical aging on decision making. Our goal is to use whole brain voxel based morphometry (VBM) analysis to determine where the gray matter volume correlates with the behavioral measure of economic error. In another study (Gilaie-Dotan, et al., 2014), we found that grey matter density in the posterior parietal cortex predicts risk attitudes with surprising accuracy. Scientists also found that ventromedial frontal lobe damage disrupts economic rationality (Camille, et al., 2011). Our ex ante hypothesis is that thinning beneath some threshold in these areas gives rise to choice stochasticity in elders age.

Methods: We recruited healthy elders and adopted the behavioral paradigm designed by Harbaugh and colleagues (2001) to estimate the number of violations of the generalized axiom of revealed preference (GARP) in each individual as a measure of these errors. In a typical decision situation subjects chose their preferred bundle, consisting of some quantity of a snack and beverage, from a larger set of bundles. For instance, they could choose "2 boxes of milk and 3 pieces of chocolate" or "4 boxes of milk and 2 pieces of chocolate". Assessing many such choices, an economically rational agent must both obey transitivity and prefer increasing amounts of any good to decreasing amounts of that same good (within reason). In sum, the task allows us to calculate the number and strength of violations of GARP to quantify the degree of irrationality in choice for each individual. We then relate this behavioral measure of irrationality to individual brain structure.

Results: Our preliminary results show that the paradigm works well. Older subjects with what would be considered normal cognitive ability according to cognitive function scales, violate GARP at different rates allowing us to rank them based on the degree of irrationality in their choice.

Conclusions: Many studies have observed that age is a crucial factor of decision making and more stochastic choices made by elder population. In this study we aim to use VBM analysis to determine where the brain structure correlates with the economic error. Ongoing imaging of 40 subjects should allow us to rapidly test our ex ante hypothesis.

Acknowledgements:
The research was sponsored from NIH-NINDS-NS054775 grant awarded to P.W.G..

Neural mechanisms of post-decisional spreading of alternatives: EEG study.

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Objective: Cognitive Dissonance (CD) theories state that preferences can be modulated by the mere act of choosing. According to CD theory (Festinger, 1957), a decision between two similarly valued alternatives creates a psychological tension (dissonance) that is reduced by a post-decisional re-evaluation of the alternatives, the chosen item being evaluated more positively and the rejected item more negatively. Some neuroimaging studies (see Izuma 2013, for a review) suggested that activity of the medial prefrontal cortex (mPFC) underlies post-decisional spreading of alternatives, nevertheless the exact mechanism of CD remains unclear.

Methods: 21 right-handed hungry participants performed a free-choice paradigm (Izuma at al., 2010), in which participants were initially asked to rate their preference for food items (snack food) using 8-point Likert scale. Next, subjects made choices between pairs of foods (Self trials in the Choice task) which varied systematically so that choices were sometimes made between two equally liked items (Self-Difficult trials), and other times between one liked item and one disliked item (Self-Easy trial). In still other trials, choices were made randomly by a computer between two equally liked items (Computer trials, control condition). Next, participants were asked to rate the original set of food items again to detect post-decisional spreading. We also recorded response-locked event-related potentials (ERP) during Self-Difficult and Self-Easy trials.

Results: Our behavioral result clearly show post-decisional spreading of alternatives, i.e. items that were rejected during Self-Difficult trials were rated significantly more negative than those rejected during Self-Easy trials. Interestingly, decisions during Self-Difficult trials were accompanied by a stronger negative fronto-central ERP similar to the Error-Related Negativity (ERN).

Conclusion: ERN has been previously associated with incorrect responses and general performance monitoring mechanism (Young at al. 2004). Overall, our results suggest that CD can be mediated by the activity of the mPFC as a part of the general performance-monitoring circuitry.

Acknowledgments: The work was supported by RSCF grant no: 14-18-02522.

A systematic comparison of models of generosity

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Objective: Decisions that affect other people's outcomes are a fundamental aspect of social behavior. In non-strategic contexts, such decision-making processes are formalized as models of "other-regarding preferences", which measure how much a person is willing to sacrifice to help or hurt others. Many models of other-regarding preferences have been proposed, but there has not been convincing evidence in favor of any particular one. Moreover, MRI studies of other-regarding preferences typically assume a model without justifying their choice. The goal of our project was to empirically identify the best model from amongst leading models of other-regarding preferences, using optimal trial design and Bayesian model selection procedures. In addition, we assessed the effect of social distance on the parameters of the other-regarding preferences.

Methods: We conducted two studies consisting of an incentive-compatible modified dictator game with two possible recipients, one a friend and one a stranger. Previous studies of generosity have handpicked trials believed to be informative about models or parameters. Here, we took a more systematic approach. In Study 1, we selected trials to maximize mutual information between the data and the model, i.e., our ability to determine which of three classes of models (Charness-Rabin, Cobb-Douglas and Rawlsian) best accounted for the behavior of our subjects. In Study 2, we selected trials to maximize mutual information between the data and the parameters within the best fitting model in our population.

Results: Study 1: Several model comparison measures identified the Charness-Rabin model as by far the best descriptor for our population. The Charness-Rabin model posits a linear utility function, with a weight on the other's welfare that depends on whether the decision maker is better or worse off; the Fehr-Schmidt model is a subclass of Charness-Rabin. Study 2: This study revealed that, regardless of context (better or worse off), the weights placed on the welfare of a friend are higher than those of a stranger. Aggregating the two populations, we observe that the pattern of weights by context is markedly different for friends and strangers: subjects tend to display classical difference aversion with strangers, with negative weights when the subject is worse off, and positive weights only when better off. By contrast, the weights for friends are typically positive in both contexts, albeit lower when worse off than when better off.

Conclusions: We interpret these results as evidence of a tendency towards prosocial difference aversion when it comes to friends and antisocial difference aversion when it comes to strangers.

Oxytocin influences taste placebo effects

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Introduction: Previous research showed that marketing actions such as branding or pricing can change the experienced utility (ExU) of an otherwise identically composed product (see Plassmann and Wager, 2014 for a review). Such effects do not only alter reported measures of ExU but also their neural signatures and related subsequent behaviors. This phenomenon has been coined "marketing placebo effects" (MPEs). Past studies revealed that the strength of the belief in the marketing action (Shiv et al. 2005), and also dispositional optimism (Geers et al., 2010) increased responsivity to placebo effects. This might be linked to studies showing that frequently used marketing cues, such as brands, high prices or organic labels, increased consumer trust in the product (Delgado-Ballester and Munuera-Alemán, 2001; Pivato et al., 2008). Oxytocin (OXT) is a hormone that has been linked to social behavior, trust, social attachment and stress relief (e.g., Ditzen et al., 2009; Kosfeld et al., 2005). Interestingly, a recent clinical study found that pain analgesia due to placebo treatments could be enhanced by the application of OXT (Kessner et al., 2013). The authors in this study argue that the effects may be driven by an increase in trust in the treating physician. Taken together, there is first evidence that OXT might play a role in placebo responses. However, it remains an open question whether these effects may generalize to other placebo-domains. In this research, we investigated whether OXT also increases MPE, that is, expectancy effects in the positive domain for every-day consumer decisions.

Methods: 113 male participants (mean age=22.8 years (SD=2.66)) were included in the study. Volunteers were randomly assigned in a double-blind procedure to either intranasal administration of OXT (Syntocinon Spray; Novartis, Basel, Switzerland) with a total dose of 24 IU, or PLC, a sodium chloride solution, that was used as sham spray. We presented three product samples across five categories in a random order and subjects tasted and rated the product's taste pleasantness and intensity. Two of the product samples were identical, but presented with a different label ("marketing label", "plain label"), the third one was a control product.

Results: First, independent of treatment, we found significant MPEs on taste pleasantness i.e., reported measures of ExU ($F(1, 549)=36.1$, $p<0.001$), and on taste intensity ratings ($F(1, 549)=20.75$, $p<0.001$). Second, the linear mixed effects regression analysis revealed that OXT increased MPE on taste pleasantness ($F(1,113)=4.1$, $p=0.045$), whereas it lowered expectancy effects on taste intensity ratings ($F(1,113)=3.9$, $p=0.05$). We did not observe a significant effect of OXT on taste ratings for the control products given only once (pleasantness: $F(1,113)=0.94$, $p>0.25$; intensity: $F(1, 113)=0.20$, $p>0.25$).

Discussion: The study provides evidence that OXT more generally influences placebo effects across domains for everyday consumption decisions. In ongoing work, we are investigating whether these effects are mediated by trust in marketing actions and what role reward processing (and through it dopamine functioning) might play for these effects to occur.

A full reference list is omitted from this abstract due to space constraints.

Emotional arousal modulates choices under uncertainty

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Objective: Research exploring decisions under uncertainty typically conflate the unique contribution of risk and ambiguity, making it impossible to differentiate the specific role of emotion in guiding these discrete choice parameters. Employing various methods, including skin conductance response and patients with lesions to the medial prefrontal cortices and amygdala—regions implicated in emotion and the adaptive choice—we investigate whether emotion plays a guiding role during decisions of uncertainty.

Methods: In Study 1 participants completed a computerized lottery task choosing between a certain payoff of $5 and a monetary lottery with a possibility of winning $5-125 or nothing. In Study 2, we ran the same lottery task in 3 additional groups: patients with lesions in the amygdala, patients with lesions in the prefrontal cortices, and matched healthy controls. During the task, each lottery was either risky or ambiguous, allowing us to assess an individual's sensitivity to known (risk) and unknown (ambiguous) monetary choices. The parameters of the lottery were systematically varied in random order, such that the magnitude of the potential win, and the probability of winning (either risk: fully stated winning probabilities of 25%, 50% and 75%, or ambiguity levels: varying levels of occlusion at 24%, 50%, and 74%) could independently influence a participant's choices. Skin conductance responses (SCRs) were recorded during the lottery presentation and subsequent choice to either engage in the gamble or take the sure $5. We derived structural estimates of risk and ambiguity attitudes by modeling the expected utility (*U*) of each option under consideration with a power utility function that takes into account the effect of ambiguity on perceived winning probability: $U(p, A, v) = \left(p - \beta * \frac{A}{2}\right) * v^{\alpha}$, where *v* is the associated dollar amount, *p* is the winning probability, *A* is the ambiguity level, α is a measure of risk attitude, and β is a measure of ambiguity attitude.

Results: In study 1 we found that when participants decided to gamble, they showed increased arousal responses for ambiguous compared to risky lotteries. A linear regression with arousal as the dependent variable and expected utility as the independent variable revealed that *U* predicted the arousal response. In study 2, we found that although patients with lesions in the amygdala and prefrontal cortex exhibited increased aversion to risk and ambiguity, both patient groups exhibited blunted arousal responses to risky and ambiguous lotteries compared to matched comparators.

Conclusions: Here we characterized the relationship between emotional arousal, the neural systems implicated in affect and value, and an individual's expected utility during risky and ambiguous choices. The results suggest a dynamic system where subjective value is modulated by emotional arousal.

Neural representations of subjective value across the human lifespan

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Humans often face decision scenarios in which the actual outcome of one or more of the available options is uncertain. Sometimes the probability that an event will occur is known (e.g., a 50% chance of gaining $10), while other times, only partial information is available (e.g., a 25%–75% chance of gaining $10), and our idiosynchratic attitudes to risk and ambiguity, respectively, guide our choices. How these attitudes change across the human lifespan, particularly in more vulnerable phases like adolescence and elderhood, and how the brain incorporates features like value, risk, and ambiguity to arrive at a unified representation of the subjective value (SV) of a given option is of great interest to economics and neuroscience alike. Here, we evaluate the neural correlates of subjective value representation under uncertainty across the lifespan.

60 participants (12–88 y.o., 35 F) made choices between a fixed reference amount (certain gain of $5) and a lottery whose magnitude ($4–$120), probability of payout (0.25, 0.5, 0.75), and degree of ambiguity (0, 0.24, 0.5, 0.74) was systematically manipulated; neural activity was concurrently measured using fMRI. The SV for each option was modeled using a power utility function with an additional ambiguity–attitude parameter, and choice data were fit with a logistic function to obtain idiosynchratic risk and ambiguity attitudes. One of the choices was randomly selected at the end of the experiment and determined bonus earnings.

We examined the timecourse of the BOLD signal in the ventral striatum and the ventral medial prefrontal cortex (vMPFC) using ROI masks from a 2013 meta–analysis of the neural correlates of subjective value. Using individual risk and ambiguity attitude parameters, we calculated the SV of each option and computed trial triggered averages of the BOLD response, separately for two SV conditions (High, Low). A mixed–design ANOVA was performed on the peak activation in each ROI, with SV condition as a within–subjects factor and age group (12–50, 51–90) as a between–subjects factor.

In line with previous research, we found that subjective value modulates BOLD activity in the ventral striatum and the vMPFC. We found no evidence for an age x SV interaction, in either ROI, suggesting that SV representation is robust from adolescence to elderhood. We did find, however, some evidence for a main effect of age in the ventral striatum, with the 51–90 group showing a decrease in overall activation relative to the 12–50 group. No evidence for such age related differences were found in the vMPFC. Future analyses will assess more fine–grained age–related differences in the precision of the SV representation in both ROIs.

Support
NIH grant R01 5R01AG033406 to P.W.G. and I.L.

A valuation-based mechanism for increased apathy following ventromedial prefrontal damage

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Objective: Apathy is a common and debilitating symptom of traumatic brain injury (TBI), characterized by the reduced performance of goal-directed behaviours. Despite its clinical significance, the mechanisms underlying apathy are not well understood. Neuroeconomic models of decision-making suggest that goal-directed behaviour is strongly influenced by stimulus valuation, and the key role of the ventromedial prefrontal cortex (vmPFC) in this process has been well established. Intriguingly, damage to vmPFC not only impairs stimulus valuation, but also increases apathy, suggesting a possible functional association between these two impairments. Here, we hypothesized that the relationship between vmPFC damage and apathy is mediated by stimulus valuation.

Methods: In the present study, 94 combat veterans with focal penetrating TBI and 21 matched combat veterans without brain damage from the Vietnam Head Injury Study completed a Becker-DeGroot-Marschak (BDM) auction task to index their valuation ability, and had their levels of apathy in day-to-day life evaluated by a close family member or friend. Our analysis proceeded in two stages: first we conducted a statistical mediation analysis determining whether vmPFC damage caused elevated levels of apathy through impaired stimulus valuation. Second, we performed voxel-based lesion-symptom mapping (VLSM) and group-based analysis to determine whether patients with damage to sectors of vmPFC that are known to compute stimulus valuation were associated with elevated levels of apathy. For both analysis stages, we contrasted vmPFC with a related brain region that was also damaged in a subset of our patient sample (dorsomedial prefrontal cortex, dmPFC).

Results: As hypothesized, the mediation analysis demonstrated significant effects of vmPFC damage on apathy and valuation, and a significant mediation effect whereby vmPFC damage increased apathy through impaired valuation. dmPFC damage was not significantly associated with apathy, valuation, nor was there evidence of significant mediation. Furthermore, the VLSM results suggested that sectors of vmPFC that are known to compute stimulus values at the time of choice were associated with impaired BDM performance and increased apathy. In contrast, patients with dmPFC damage an intact vmPFC did not differ from controls on either of the two target measures.

Conclusions: Our results provide evidence that impaired valuation is one source of increased apathy in patients with vmPFC TBI, underscoring the critical importance of stimulus valuation in driving goal-directed behaviour.

AN EVENT-RELATED ANALYSIS OF THE TRADERS DECISION-MAKING BY USING ICA

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INTRODUCTION: The objective of this article is to identify, with the aid of an electroencephalogram (EEG) and by using a multivariate statistical tool called independent component analysis (ICA), the areas of the brain and their interconnection associated to the Traders' decision-making process. In order to assess such activity, a sample of forty (40) experienced traders were used, both divided equally into 50\% male and 50\% female. In Lima Filho (2014), it was found through brain mappings that such traders tend to make decisions by using an associative based rule process instead of any of analytical form, as posed by much of the classical financial literature.

METHODOLOGY: Volunteers participated in a simulation of investments on the São Paulo Stock Exchange - BM & FBovespa - whilst electroencephalogram (EEG) epoch was recorded. The total simulation time lasted 50 minutes, also subdivided into 25 minutes, primarily related to a bull market and then a down market. Thus, the purpose was to characterize brain activity patterns associated with the purchase, sell or hold decision of a set of shares comprising two experimental portfolios (called A – Upward Market and B - Downward Market). According to Onton and Makeig (2006), "electrode locations are at best quite crude indicators of the locations of even the strongest underlying cortical sources", resulting into EEG recordings with 'low spatial resolution.' Since we aim to isolate the areas of the brain that were activated, a way of tackling this problem is making use of the Independent Component Analysis (ICA). They decompose the data (input) into a set of components which are independent and explain the data itself and its variability by writing them as a linear combination of such factors.

RESULTS: Traders group proved to have a more heterogeneous decisions, given high standard deviation, with even negative values. It is also worth mentioning that the average decision time this group was fast, a total of 49.2 seconds/decision. This may also suggest a time discount regarding the expected reward, as advocated by Muller and Cohen (2001), since the activation of the decision-making process occurred late in the frontal cortex and prefrontal right. Additionally, this indicates an heuristic / associative system domain. The most interesting was the fact that the purchase and sale orders have triggered different neuronal circuits, even in a predictable market, as explained by Rocha (2013).

Acknowledgements: I would like to thank you the Laboratory of Medical Informatics and A+ Recrutament for supporting with the necessary equipment s and volunteers.

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Ventromedial Patients Demonstrate Errors in Theory of Mind and Social Cognition

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Objective: Individuals with damage to ventromedial prefrontal cortex (VMPFC) exhibit changes in social decision-making. They are more likely to reject unfair offers in the Ultimatum Game (Koenigs & Tranel, 2007), provide less generous offers in the Dictator Game (Krajbich et al., 2009), and endorse more utilitarian answers in moral dilemmas (Koenigs et al., 2007). Though these effects have been ascribed to deficits in emotion regulation, damage to VMPFC does not impair regulation of transient responses to emotional stimuli (Gillihan, et al., 2011). Here we explore an alternative explanation, that damage to VMPFC impairs theory-of-mind (ToM) and social cognition (Beer et al., 2003; Leopold et al., 2012; Shamay-Tsoory et al., 2005).

Methods: 8 patients with focal lesions to the ventromedial frontal lobe (VMF), 9 controls with lesions in the dorsolateral frontal lobe (DLF) and 11 age-matched healthy controls (HC) were tested on 4 ToM tasks. Stone et al.'s ToM task (1998) presents stories with or without a social faux pas, in which the subject identifies if and why something awkward happened. Winner et al.'s ToM task (1998) contains stories in which a person either believes no one knows they wronged another and lies to avoid getting caught, or they know they are caught but make an ironic joke to cover up their embarrassment, and subjects identify which the person believes. German & Hehman's ToM task (2006) has short stories with or without false beliefs, and with approach or avoidance motives, and subjects must predict what someone will do. Finally, Rutherford's ToM task (2004) has four complex stories, involving zeroth order to third order beliefs, and subjects determine what people know.

Results: VMF patients show several deficits in the ToM tasks. In the faux pas task, VMF patients were significantly worse than HC and DLF. Surprisingly, this was driven by false alarms - finding faux pas that did not exist ($p < 0.05$). VMF patients also failed to identify ironic jokes compared to DLF patients ($p < 0.01$). Further, VMF patients predicted behavior significantly worse than the HC ($p < 0.01$). Notably, patients performed similarly to HC and DLF patients in the ToM questions ($p > 0.10$) that probe simple identification of true or false beliefs.

Conclusions: We find that VMF patients perform significantly worse on several aspects of ToM. VMF patients struggle to determine acceptable social norms, and have trouble explaining or predicting behavior, though they can accurately identify true and false beliefs. Our findings indicate the importance of these abilities in social behavior, and suggest an alternative conceptualization of the role of VMPFC in social decision-making.

Do we need to treat risk? Attitudes toward risk and ambiguity in opioid addiction

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Objective: Drug addicted individuals are thought to be excessively reckless and risky, but the relevant factors that drive these behaviors are poorly understood. Economics provides a set of tools to quantify at least three factors that distinctly contribute to an individual's propensity for risk taking: their tolerance of known risk (technical risk attitude), their tolerance of ambiguous or unknown risk (ambiguity attitude), and the randomness in their decision process (stochasticity). Therefore, to more fully understand the behavior of opioid users in risky situations, in the present study we focused on these three factors, which have not been the subject of previous experimental decomposition in addiction although such a decomposition may have important implications for understanding and potentially treating this disorder.

Methods: Individuals seeking treatment for an opioid use disorder at a large urban hospital completed a task in which they chose between a certain $5 and a lottery offering a chance to win more than $5 or nothing. Across trials, we varied the magnitude of the potential win, the probability of winning, and the level of ambiguity (how much was known about the probability of winning). The task was incentive compatible meaning that subjects were paid according to their actual choices.

Results: Preliminary data suggest opioid users are more risk tolerant than they are ambiguity tolerant, as has been observed in health. We find good fits of a modified power utility model that treats ambiguity as a subtrahend term to probability, suggesting the assumptions of this model hold for the behavior of this group. Analyses that do not assume a specific model also support this claim: users are more likely to choose the lotteries when the amount and probability associated with these lotteries is higher, and the ambiguity lower. Data collection in an age and wealth matched community sample of nondrug users is ongoing. However comparison with parameters obtained in two independent published healthy adult data sets suggests opioid users may deviate more from health in their tolerance of ambiguity (~2425% more tolerant) than of risk (~016% more tolerant). No apparent differences are observed for stochasticity, suggesting that a diminished "quality" of decision making is not driving these differences from health.

Conclusions: These initial data raise the possibility that there may be ordering in the relative contribution of these individual factors to the behavior seen in addicts (ambiguity attitude > technical risk attitude > stochasticity). Our ongoing work seeks to validate this hypothesis.

Acknowledgements:
This study was funded by the NIH, grant #'s 1R01DA038063 and 5T32MH1952422.

Context can induce seeking behaviour in punishment conditions

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Objective:

While the process of learning to seek rewards is fairly well understood both computationally and neurobiologically, the process of learning to avoid punishment is less clear. In this project we use a probabilistic instrumental learning task that presents a 2x2 factorial design, and is followed by post-learning assessment of option values, to investigate if humans in a punishment domain always use avoidance behaviour. The 2x2 factors are reward/punishment x factual outcome (partial feedback) /factual&counterfactual outcome (complete feedback).

Methods:

To investigate this we use computational methods to explain their behaviour, as well as employ fMRI and MEG as neuroimaging methods to qualify the underlying mechanisms.

Results and conclusions:

Our results show, that in the punishment condition participants use both seek and avoidance behaviour, and that these different approaches depends on the context of the expected punishment.

This we show behaviourally as the participants prefers a low probability losing option over a low probability winning option in the post-learning assessment of the value of choice options encountered in the complete feedback condition. We interpret this as the participants learning to seek the low probability losing option, rather than avoid the high probability option. Our interpretation is backed up by the neuroimaging data that on a neural level shows a shift in negative outcome encoding from the anterior insula to the ventral striatum, indicating that the recruitment of the approach system rather than the avoidance system.

Future work will include analysing the MEG data using model-based methods, and analyse the two imaging datasets together to qualify when during the learning process the shift from avoidance to seek behaviour occurs.

Inter-individual normalization of value representation in the human brain

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Introduction: Neuro-economics investigates the neural basis of value-based decision-making. Values, derived from explicit ratings or binary choices, have been robustly mapped in a limbic network, with the ventromedial prefrontal cortex (VMPFC) as a core component. We investigated how behavioral inter-individual differences in valuation translate in brain activations (BOLD signal) in the VMPFC.

Methods: We posit two hypotheses to model how inter-individual differences in behavioral values translate in the BOLD signal: 1) the proportional hypothesis, where the BOLD signal proportionally scales with values, and 2) the normalization hypothesis, where the BOLD signal is bounded between ceiling and flooring levels, independent from the individual range of values.
Under the GLM framework, brain activations are summarized by individual unstandardized coefficients of regressions (β_k) between BOLD and values (X). We derived, for our two hypotheses, statistical relationships between the (β_k), the linear dependency between BOLD signal and values (a partial R_k), and the standard deviation ($\sigma_{X,k}$) of the distribution of the behavioral values -, in conditions were brain data is analyzed with native (X) or standardized values (z-scored X). Then, in the case where we neglect individual differences in R_k expected to be independent of $\sigma_{X,k}$, we have:

- In the native condition, under the proportional hypothesis: $\beta_k \propto \alpha$
- In the native condition, under the normalization hypothesis: $\beta_k \propto \frac{\alpha}{\sigma_{X,k}}$
- In the standardized condition, under the proportional hypothesis: $\beta_k \propto \sigma_{X,k}$
- In the standardized condition, under the normalization hypothesis: $\beta_k \propto \alpha$.

We re-analyzed 3 fMRI datasets involving subjective values attributed to different stimuli (pictures of faces, houses and paintings, videos of objects, sentences describing prospects), and tested those predictions.

Results: In an anatomically defined VMPFC ROI we found that β_k was significantly correlated with $\frac{1}{\sigma_{X,k}}$ in the native condition (all datasets: $p<0.05$). We found no significant correlation between the standardized β_k and $\sigma_{X,k}$ in the standardized condition. Our results therefore robustly support the normalization hypothesis.

Conclusion: We report an inter-individual normalization effect in the representation of values in the VMPFC. This constitute an extension of the recently described intra-individual "range adaptation" property of the same value-representation mechanism. This result has important consequences for the interpretations of group-level statistical inferences made in parametric and model-based fMRI studies, such as between group differences and inter-individual correlations.

Acknowledgments:
ML is supported by an UvA ABC Talent Grant. ML & SP are supported by EU Marie Skłodowska-Curie Individual Fellowships .
ML and SP acknowledge Mathias Pessiglione for granting access to the fMRI datasets.

Adaptive Learning Rates in a Continuously and Gradually Changing Environment

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Objective: Delta rule models are often employed to describe learning behavior. A delta rule with a fixed learning rate is the optimal solution to the problem of estimating a continuously and gradually changing quantity from noisy observations. The Kalman filter describes how the learning rate in such environments should be set depending on the observation noise and the drift rate of the quantity of interest in a given environment. Using a cognitive task in which learning rates were directly observable on every trial, we investigated how well people's learning rates corresponded to the Kalman filter solution across continuously changing environments that differ in noise and drift rate.

Methods: Participants performed a predictive inference task that required them to estimate the environment's state only via noisy observations. In this game, participants placed a bucket along the horizontal axis of the screen in order to catch bags of coins that dropped from an occluded helicopter. Participants were paid according to the number of coins they caught. The helicopter's movement was governed by a Gaussian random walk (drift), and the position of the bag drop was sampled from another Gaussian distribution centered on the position of the helicopter (noise). This task allows direct trial-by-trial measurement of learning rate since both an error (how far was the bag from the bucket on this trial) and an update (how much did the participant move the bucket from its current position on the next trial) are observed on each trial.

In experiment 1, optimal learning rates were manipulated by adjusting the observation noise (variance of the bag drop), with a higher optimal learning rate proscribed when noise was low. In experiment 2, optimal learning rates were manipulated by adjusting the drift rate (speed of the helicopter's random walk), with a higher optimal learning rate proscribed when drift rate was high. 32 people participated in each experiment. All participants completed two blocks in a low optimal learning rate environment and two blocks in a high optimal learning rate environment, alternated and counterbalanced.

Results: Although the participants' learning rates were overall higher than the optimal learning rates, they exhibited two features of the Kalman filter solution. First, learning rates were significantly higher in environments where noise was low or drift rate was high. Second, participants maintained a constant learning rate throughout the task that does not vary systematically as a function of error size.

Conclusions: In continuously and gradually changing environments, people adjust their learning rates in an adaptive manner depending on the noisiness and the speed of change of the environment.

Acknowledgements:
This study was funded by the NIH, grant # R01MH098899

Propranolol reduces reference-dependence in intertemporal choice

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Objective: Many decisions involve weighing immediate rewards against future consequences. In such intertemporal choices, people often choose smaller, immediate rewards over larger delayed rewards. Although it has been suggested that emotion underlies the tendency to favor immediate rewards, we have previously shown that emotional arousal (specifically, pupil dilation responses), as well as choices, in intertemporal choice tasks are reference-dependent. Arousal increases when less predictable rewards are better than expected, whether those rewards are immediate or delayed. Moreover, when immediate rewards are more variable than delayed rewards, individuals tend to be patient. When delayed rewards are more variable, people are more impulsive. These findings suggest that emotional arousal underlies sensitivity to the recent history of offers in intertemporal choice.

Methods: We tested whether emotional arousal causes reference-dependence in intertemporal choice by pharmacologically blunting arousal responses using propranolol, a beta-adrenergic receptor antagonist. Thirty-seven subjects participated in a two-day double-blind within-subjects design. On each of two days (once on 80 mg propranolol, once off), they performed an intertemporal choice task with three conditions: Immediate Vary (immediate rewards were more variable than delayed rewards); Delay Vary (delayed rewards were more variable than immediate rewards) and All Vary (immediate and delayed reward values were equally variable). We hypothesized that individuals would be more impulsive in the Delay Vary than in the Immediate Vary condition, and that propranolol would reduce this difference in impulsivity.

Results: Replicating previous work, in the placebo condition, participants were significantly more impulsive in the Delay Vary than the Immediate Vary condition (t_{26}= 3.19; p = 0.004). This effect was weaker when individuals were given propranolol (t_{30} = 1.13; p = 0.27). The influence of propranolol on behavior may depend on body mass index (BMI) due to the drug's highly lipophilic nature. Indeed, the difference between conditions was greatest in those with low BMI, while high BMI individuals displayed similar reference-dependence on and off the drug ($F_{(1,24)}$ = 4.32; p = 0.048). Concordantly, propranolol reduced pupil dilation responses in low BMI individuals, but not in those with high BMI ($F_{(1,34)}$ = 6.24; p = 0.018).

Conclusions: These results suggest that emotional arousal underlies sensitivity to the choice context during intertemporal choice. This is consistent with literature showing that arousal is related to reference-dependence in decisions under uncertainty.

Acknowledgements:
This study was funded by NIH #R01AG039283 to EAP and NSF GRFP to KML.

Title: Treating Impulsivity: Temporal Discounting in Heroin Users undergoing Treatment

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Keywords: Addiction, Delay Discounting, Temporal Discounting, Intertemporal Choice, Risk, Impulsivity, Opioid, Opioid Use Disorder, Longitudinal, Heroin, Methadone, Decision-Making, Incentive Compatible.

Objective: Impulsive decision-making is a hallmark of addiction and, in the case of opioids like heroin, seems to be modified with treatment consisting of standard counseling and pharmacological maintenance therapy. Previous studies have used intertemporal choice procedures to measure the discount rate as a quantitative means for estimating impulsivity. However, whether discount rates can be used to predict and accurately track opioid use disorder patients' path through treatment remains a pressing open question. Its usefulness as a predictor of relapse or recovery is of critical importance. Opioid use is skyrocketing and opioid use disorder has one of the highest rates of relapse across substances of abuse. We conducted a longitudinal within-subjects study with repeated measures of temporal discount rates in a cohort of patients starting treatment for mild to severe opioid use disorder.

Methods: Repeated measures (weekly and bi-weekly) of both an intertemporal choice task and a risk attitude task were made in a group of patients starting their treatment at Bellevue Hospital's Methadone Treatment Program. Both tasks were fully incentive compatible. A group of matched healthy controls performed the same tasks. The Time Line Follow Back questionnaire was used to track drug use between sessions, including use of patients' prescribed maintenance medication. Urine testing confirmed these reports. Subjects' choices in the behavioral tasks were fitted with a standard hyperbolic discount model and a second hyperbolic discount model, which incorporated a risk parameter to account for nonlinearities in the utility function.

Results: As previously reported, opioid use disorder patients have significantly higher discount rates compared to healthy controls. Preliminary results from our pilot study indicate discount rates follow each patient's clinical state through recovery, decreasing progressively with abstinence. Interestingly, discount rates also correlate with relapse events, peaking when these events occur. Data collection in a larger sample is ongoing.

Conclusions: We conclude that temporal discounting, when assessed repeatedly over the course of treatment, could be used as a behavioral signature of patients' evolution and potentially serve as a useful predictor of prognosis and treatment adherence for opioid use disorder.

Acknowledgements: This study is funded by the NIH, grants #1R01DA038063 and #5T32MH1952422.

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Role of prior preference in shaping the neural format of subjective value

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Decision theory assumes that when faced with a binary choice, individuals first assign subjective values to each option, and then compare the two values to select the best. Understanding how option values are encoded and compared is a key objective for neuroeconomics. A large body of evidence suggests that activity in the ventromedial prefrontal cortex (vmPFC) correlates with option value. However, the frame of value representation remains unclear: according to some studies vmPFC activity might represent pre-choice variables such as the sum of the two option values, in others the vmPFC would represent a decision variable such as left minus right or attended minus unattended option value, and in a last set of studies the vmPFC is suggested to represent a post-choice variable such as chosen minus unchosen option value.

We propose an alternative hypothesis, according to which the frame of value coding in the vmPFC is imposed by a default policy. This means that the brain reframes economic binary choices (A vs. B) as stay vs. switch choices. This hypothesis makes predictions at both the behavioral and neuronal level. At the behavioral level, it predicts that one set of options corresponding to the default policy should be chosen more often and more quickly than others. At the neural level, it predicts that the vmPFC should encode the value of the default option.

In order to test this hypothesis, we developed a task involving subjects (n=24) choosing between two options pertaining to different categories (e.g., jazz vs. rock CD). We inferred the preference between categories from the mean of likeability ratings assigned to every item prior to performing the choice task. Choice data confirmed that items belonging to the preferred category were chosen more often and more quickly, even when regressing out the difference in likeability ratings. This behavior was well captured by a drift diffusion model that included a start bias in favor of the preferred category. FMRI data showed that vmPFC activity encoded the value of the option belonging to the preferred category (the default option), irrespective of choice. This framing of value coding was not related to the pattern of gaze fixations, since eye-tracking data showed that subjects looked equally at the default and alternative options. We therefore conclude that prior preferences can elicit a default policy that frames the neural representation of option values during binary choices.

From Web to Wardrobe: Joint Modeling of Eye Movements and Decisions

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Objective: Current models of eye movements during decision making treat eye fixations and saccades as either exogenous inputs or decisions, without linking them to the final choice response. The most widely accepted account of visual attention during choice postulates the integration of goal-directed and stimulus-driven brain networks to focus and reorient attention. We collected eye movement and choice data in an online shopping task in which we gave subjects different shopping goals to manipulate attention reorientation. Drawing upon the optimal search literature from economics, we developed a model to jointly account for eye movements during search and choice.

Methods: We exogenously manipulated the likelihood that stimulus-driven attention would reorient the search process during online shopping at the American Apparel website by giving 80 female subjects either a hedonic or a utilitarian goal for a purchase in the same product category. Visual attention was captured using eye-tracking. We build a model of eye fixation choices from the website's landing page up until the first click. Our model captures how product fixations are sequentially related, accounts for information acquisition through visual attention, and incorporates a stopping rule framework characterized by traditional economic models of optimal search.

Results: Initial comparisons of the two goal conditions suggest that utilitarian shoppers exhibit more focused goal-directed attention (e.g., head directly to the goal category), while hedonic shoppers exhibit more stimulus-driven attention and reorient their goals more during search (e.g., search the landing page more extensively, view a wider range of products). Our model captures these dynamics and also separates heterogeneity and information value as determinants of the stopping rule used by subjects.

Conclusions: These results demonstrate that shopping goals can influence search patterns. In future work, we will examine the remainder of the shopping trip beyond the first click, including clickstream and shopping cart items. We have also collected mobile eye-tracking data from a parallel in-store study. We plan to compare search patterns for online and in-store shoppers, enabled by our new method of self-coding eye-tracking video.

Acknowledgements:
This study was funded by a grant from the Jay H. Baker Retailing Center at Wharton. Eye-tracking equipment and software was provided by the Wharton Behavioral Lab.

The effect of economic competition on the neural mechanisms of decision-making

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Objective: Behavioral economics has extensively studied how people make economic decisions in environments with different levels of supply and demand (i.e. with different levels of economic competition). However, the neural mechanisms underpinning such decisions remain unidentified. Here we study the neural mechanisms underlying decisions in different conditions of economic competition. Additionally, we aim to investigate the learning processes that lead to adaptive bargaining strategies, and how these are modulated by the degree of economic competition.

Methods: Fifteen subjects played the role of buyers in simultaneous games against different numbers of prerecorded buyers and sellers. We used a modified Ultimatum Game (double auctions) in 50-minute 3T functional magnetic resononace imaging (fMRI) scanning sessions. Overall, the game allowed us to identify the effects of competition (number of sellers and buyers) on subjects' willingness to pay (the size of bids).

Results: Behavioral results demonstrated that subjects adjusted their trading price during the game based on the perceived competitiveness of the environment. We observed a progressive, yet incomplete convergence towards the optimal strategy predicted by a game-theoretic analysis. Intriguingly, the data hint at two separable learning processes involved: the subjects' overall scales of bid values are mainly influenced by the market environment, whereas subjects' trial-by-trial adjustment of bid values instead display a skewed distribution modulated by the outcome of the previous trial. Preliminary fMRI data analysis showed significant differential activations and differential dynamics of the activity in the basal ganglia in the different competitive conditions.

Conclusion: The results of the pilot study indicate that people learn to alter trading price based on the perceived competitiveness of the environment and suggest a profound role of the dopaminergic system in behavioral adaptations during economic competition.

Acknowledgements: This work was done within the framework of a subsidy granted to the HSE by the Government of the Russian Federation for the implementation of the Global Competitiveness Program.

Color, Risk Preferences and Investment Decisions

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Objective: Financial service providers and media use various colors to communicate financial information, such as stock prices. The commonly used colors are black, blue, or the combination of red and green for losses and gains. Recent research on the psychology of color shows that color in general, and red in particular, can influence behavior (Elliot and Maier, 2007). The color red is associated with warnings through implicit learning (stop signs, bad grades; Elliot and Maier, 2007) and with anger (e.g. redness of the face; Changizi, Zhang, and Shimojo, 2006). We here examine whether and how use of the color red in communicating financial information affects risk preferences and the investment decisions of traders.

Methods: Two experiments were conducted in which participants made financial decisions under uncertainty. In Experiment 1, participants chose between lotteries whose outcomes were presented in black, red, or blue. In Experiment 2, participants viewed stock charts whose trends were similarly shown in black, the red/green combination, or blue, while they reported attitudes toward the stocks, made investment decisions over the stocks, and forecasted future price trends.

Results: Our results show that the color red is associated with increased risk aversion in the lottery task: subjects are less likely to make risky choices when their downsides are shown in red than when shown in black or blue. In addition, from the stocks experiment, we found that the color red negatively influences attitudes toward and intention to purchase stocks and reduces future price forecasts.

Conclusions: We show that the use of colors to communicate financial information affects investor decision making. Specifically, using the color red increases risk aversion and decreases forecasts of future stock prices. These findings have implications for stock market anomalies, such as stock price momentum, market bubbles, and crashes.

Dissociable decision making across prospective gains and losses: non-reflective risk preferences and differential choice strategies

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Objective: We investigated the relationships between individual risk preferences and choice strategies across the gains and losses domains during economic decision making. While prior theories and empirical studies suggest people are, on averge, risk averse for gains and risk seeking for losses (Kahneman & Tversky, 1979, 2000), it is unclear whether preferences across domains are correlated (reflection effect). Are risk preferences in the losses domain a simple transform of preferences in the gains domain? Additionally, what is the relationship between these preferences and the information participants utilize to make their choices? Here, we find that preferences are uncorrelated across domains, choice strategies are correlated across domains, and that choice strategies are correlated with risk preferences in both domains..

Methods: Participants (N = 104, 57M, age = 23 ± 2.5 yrs) performed a two-alternative forced choice monetary decision task (Kurnianingsih et al., 2015), choosing between certain and gamble options with varied absolute value and probability. Risk preferences for each domain were quantified as both power function and risk premium metrics, with very high correlations between these measures and similar results. Choice strategy was quantified in each domain to determine the relative influence of two competing trial factors: 1) relative expected value (rEV) and 2) probability of winning (pWIN) the gamble.

Results: In the gains domain, participants were significantly risk averse. In the losses domain, individuals were weakly risk seeking. Importantly, there was no significant correlation between risk preferences across the gains and losses domains, contrary to the theorized reflection effect. For choice strategies, we find significant correlations in the use of the maximizing rEV information across domains, but with significantly higher use for losses. Interestingly, in both domains, participants who relied more on the maximizing rEV information were more risk neutral, suggesting that enhanced use of the rEV information corresponds to equating value and utility maximization.

Conclusion: Our findings suggests that the cognitive/neural mechanisms for gains and losses are dissociable, reinforcing the importance of seperately investigating gains and losses decision making. We note that such dissociability may explain robust behavioral differences across domains, such as the framing effect.

Acknowledgments:
This research is supported by NUS Grants WBS R-581-000-123-133 and WBS R-581-000-133-112 to OAMG.

Value to utility transformations: the dorsomedial prefrontal cortex encodes subjective value modulation

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Objective: We investigated the neural mechanisms of the value to utility transformation, localizing this computation to the dorsomedial perfrontal cortex (dmPFC).

Methods: We quantified the specific value to utility transformation, **utility = *f*(value)**, of each participant utilizing a risky economic decision making task in the fMRI scanner. Participants (N=30, 15 males, age = 22 ± 1.74 yrs) performed two-alternative forced choices (Kurnianingsih et al., 2015), between certain and gamble options with varied absolute value and probability. We focus on the gains domain, with choices between certain monetary gains and gambles composed of a possible gain and a zero outcome.

Results: The subjective value transformation, ***f***, of each participant was quantified as the degree they modulated the value of the gamble due to outcome uncertainty. On average, participants diminished the value of the gamble (risk averse), but with a wide range of values for ***f***.

To identify the 'best' **value** formulation encoded in the brain, so that this regressor could be utilized to localize ***f*(value),** we modeled value across trials in three different formulations, 1) the relative value of options, 2) the chosen value, and 3) the relative value of the chosen and unchosen options. We found evidence that all three forms are encoded, using an unbiased ROI in the vmPFC, based on the Bartra et al. (2013) meta-analysis. We therefore continued our analyes robustly by examining each formulation in independent models.

To identify the brain region responsible for the value to utility transformation, we performed a covariate analysis, applying individual preference values, ***f***, upon each value regressor. This identifies the neural encoding of ***f*(value)** – neural regions that encode a linear value signal whose slope is determined by the specific value to utility transformation each individual is performing. All three models indicated a single cluster of voxels within the dmPFC. Functional connectivity analyses indicate that this region is positively connected with the dorsolateral prefrontal cortex (dlPFC) and negatively connected with the nucleus accumbens, which we interpret to suggest that the value to utility transformation (***f***) is 'set' by contextual inputs from the dlPFC and outputs to reward regions.

Conclusions: We show that the dmPFC specifically encodes the information necessary to perform the value to utility transformation. This finding provides a clear computational function for the dmPFC, and can explain prior studies that have implicated the dmPFC in various components of decision making.

Acknowledgments:
This research is supported by NUS Grants WBS R-581-000-123-133 and WBS R-581-000-133-112 to OAMG.

Single administration of testosterone impairs cognitive reflection in men

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The male sex hormone testosterone (T) is produced in the male testes and affects physiology, brain development, and behavior throughout life. T is released in response to external stimuli (e.g., the presence of an attractive mate), modulating physiological and cognitive processes context-sensitively. In animals T is causally associated with instinctive behaviors such as aggression and mating.

The current study uses a dual-process framework to investigate the effects of T on human decision-making. As T levels are correlated with impulsivity, aggression and disinhibition in human, we hypothesized that T reduces deliberate decision-making processes ("system 2") and increases reliance on automatic, intuitive processes ("system 1").

In the largest administration study to date, 243 human males received either T or placebo under a double blind protocol and returned to the lab five hours later, when the treatment group experienced elevated T levels. We tested the effects of T using the cognitive reflection test (CRT), a 3-item questionnaire that assesses individuals' ability to suppress intuitive and spontaneous *incorrect* answers in favor of correct answers that requires cognitive deliberation. Subjects completed the test without time pressure and received $1 per correct answer, plus a $2 bonus for correctly solving all questions. Subjects performed an additional task measuring their math skills, where they had five minutes to add as many sets of five two-digit numbers as possible and received $1 for each correct answer.

In line with our prediction, the T group had significantly lower scores in the CRT compared to placebo (20% less correct answers on average, $p<.003$), and T treatment had no impact on arithmetic skills ($p>.80$). Crucially, math scores strongly predicted subjects' CRT scores, and T's effects were robust to controlling for math skill, age, mood and the levels of 14 other hormones measured using post-treatment saliva samples. Finally, the effect was significant for each of the three CRT questions in isolation, and T subjects responded faster when providing incorrect answers - demonstrating that subjects adopted their incorrect intuitive answers more rapidly under T treatment.

Taken together, our results provide converging evidence that heightened T levels are causally associated with reduced deliberative decision-making in humans, illuminating on a cognitive mechanism underlying the context-sensitive influence of T on human behavior.

Neural Correlates of Delay Discounting Alterations Associated With Trauma Exposure

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Objective: The subjective value of monetary rewards declines with increasing delays. Accelerated delay discounting (DD) occurs in individuals with externalizing problems and impulse control disorders. There is growing interest in DD as a marker of altered decision-making in stress-related disorders, including posttraumatic stress disorder (PTSD). We hypothesized that steeper DD would be associated with greater symptom severity and reduced reward sensitivity (anhedonia) following trauma exposure, as well as with volume alterations in reward-related regions (basal ganglia) and structures implicated in PTSD (hippocampus & amygdala).

Methods: Participants were 18 adults who endorsed a DSM-IV PTSD Criterion A traumatic event. They completed the Clinician Administered PTSD Scale (CAPS), the Snaith-Hamilton Pleasure Scale (SHAPS), and a computerized DD task. Subcortical volumes were derived from MRI scans using Freesurfer's segmentation procedure. Regions of interest were examined, including basal ganglia regions, hippocampus, and amygdala (controlling for total intracranial volume). Mediation analyses were conducted using bootstrap methods via the Process macro in SPSS, controlling for age and sex.

Results: DD rates were higher in individuals reporting greater re-experiencing symptoms on the CAPS, and in those reporting greater anhedonia on the SHAPS. There was no significant association between DD and avoidance or hyperarousal symptoms. After covarying for age and sex, the relationship between DD and re-experiencing symptoms was completely mediated by anhedonia. Individuals with higher DD rates showed volume reductions in the hippocampus and putamen. The relationship between DD and hippocampus/putamen volumes was not significantly mediated by CAPS total scores, CAPS re-experiencing symptoms, or anhedonia.

Conclusions: These results contribute to an emerging body of evidence regarding alterations in the DD rate in stress-related disorders. Higher DD rates are associated with key symptom dimensions following trauma exposure; we provide evidence that this relationship is driven by altered reward processing and contributes uniquely to alterations in subcortical volumes. These findings are discussed in terms of the potential for inclusion of DD as a candidate intermediate phenotype.

Acknowledgements:
This study was funded by the NIMH, grant # 5R01MH096987.

Evaluating the neurobiology of strategic coordination in non-human primates

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Coordination and cooperation depend on effective social communication. Deficits in social skills and communication attend disorders like autism. Deciphering the neural basis of social coordination and communication is thus a priority. In humans, brain areas linked to both social behavior and reward are activated by cooperation. The neural processes indexed by these blood flow signals, however, remain unclear. We previously reported neurons in anterior cingulate cortex and amygdala signal vicarious reward in monkeys when they choose to reward another monkey. Such signals may inform computations mediating coordination and cooperation.

To test this idea, we developed a new task based on the classic "chicken game." Two monkeys (M1 & M2) face each other across a shared monitor. Two colored annuli framing random dot motion arrays and 4 response targets are presented. Color indicates the annuli and targets belonging to each monkey. On ½ of trials, the larger reward (denoted by visual tokens) lies opposite the controlling monkey behind the opponent's annulus; smaller rewards lie to the left. To obtain the larger reward, M1 goes straight, but if M2 also goes straight the annuli collide and neither monkey gets reward. On some trials, a "cooperation bar" allows both monkeys to obtain larger rewards only if both choose to go left. If only one monkey yields he receives a smaller reward. On some trials, dot motion coherence is randomized to obscure intention signals.

When playing a computer opponent, monkeys played the pure Nash equilibrium strategy of maximizing reward by choosing the left target when it offered more reward, regardless of the opponent's choice. When the straight target gave more reward, they played a mixed Nash equilibrium strategy by choosing straight unless the computer opponent signaled it would go straight; then, monkeys chose the left target and obtained less reward. Monkeys' deviated from the Nash equilibrium strategy when playing a live monkey opponent by going straight more often regardless of reward size or the opponent's choice. This behavior depended on both social dominance and information about the opponent's intentions. High-ranking monkeys challenged low-ranking monkeys, who tended to yield. Mid-ranking monkeys switched strategies depending on whether the opponent was higher or lower ranking. When intention signals were obscured, monkeys collided thrice as often as when intentions were signaled clearly. These findings demonstrate strategic, competitive behavior in monkeys that depends on both social context and communication, thus validating our task as an effective tool to determine the neural basis of social coordination and cooperation.

Patients with Parkinson's Disease Fail to Use Memory to Guide Decisions Independent of Feedback

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Objective: Much evidence indicates that the basal ganglia (BG) are required for learning stimulus outcome relationships based on feedback. In many of these studies however, it is difficult to dissociate learning deficits from deficits in using learned information for action choice; in other words, whether deficits seen in patients with BG disease such as Parkinson's Disease result from faulty learning or faulty performance is unclear. Therefore, an alternative hypothesis of BG function is that it plays a role in making already established memories available to drive choices of actions independent of feedback, including feedback based on value or reward.

Methods: We developed a 2-alternative forced choice task in which patients with Parkinson's disease (PD) and healthy subjects made decisions about the orientation of Glass patterns. We manipulated the strength of visual information contained in the stimulus (coherence) and also the statistics of the stimulus occurrence by making one orientation more probable then the other (prior). Correct decisions were indicated with auditory feedback.

Results: When we presented two differently colored stimuli, randomly interleaved, one associated with an equal prior (50:50) and the other with an unequal prior (75:25), we found that whereas healthy subjects used the prior correctly when sensory information was uncertain ($N = 14$ control vs bias: $p < .05$), patients with PD failed to do so ($N = 14$ control vs bias: $p > .05$), consistent with a deficit in either feedback learning or in performance. To separate learning from performance we manipulated the task in two ways. First, we used a stronger (yet still implicit) prior and we found that both healthy subjects and patients with PD learned the prior and used it to make decisions when sensory information was unavailable ($N = 10$ control vs bias: $p < .05$); but patients with PD did not use it optimally, rather they perseverated. Second, we informed the subjects about the presence and the type of prior explicitly before the start of the experiment. Under these conditions, the requirement for learning is eliminated and only performance is assessed. We found that whereas healthy subjects were able to take advantage of the explicit instruction ($N = 17$ control vs bias: $p < .05$); patients with PD were impaired ($N = 7$ control vs bias: $p > .05$).

Conclusions: Taken together, our data indicate that patients with PD can learn using feedback to guide decisions in the absence of clear sensory information, but are impaired at *using* the previously learned information to guide those decisions. These results have implications for understanding other symptoms seen in PD such as paradoxical movement.

Preferences for foods can be predicted reliable across category and across time from different regions in prefrontal cortex: a longitudinal fMRI study

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Objective:
Regarding the prediction of preferences by means of multivariate pattern analyses (MVPA) using fMRI, it is still rather unclear how stable these classifications work across time and how important individual differences are. To answer these questions we performed a longitudinal fMRI study using MVPA techniques in two distinct food categories.

Methods:
Forty participants were asked about their preferences regarding twenty different chocolate bars and salty snacks by means of a binary forced-choice decision paradigm prior to the fMRI task. In the scanner, subjects saw only one product per trial (passive viewing) followed by a demanding visual fixation task (distractor). The whole experiment was repeated after two weeks. A linear support vector machine was trained to predict product preferences for salty snacks and chocolate bars within and across category separately for each subject. This classification was done separately for the first and the second time point as well as across both experiments for testing the temporal consistency of preference decoding. To determine reliable regions for preference decoding in each subject, classification analysis was performed on several subregions of the PFC. Each subject was tested individually for statistical significance based on permutation testing.

Results:
Classification based on the data from the first experiment: Within one food category preferences were predicted with accuracies ranging from 59% to 63%. Across different food categories preferences were predicted with accuracies ranging from 59% to 61%. The subregions of the PFC being predictive of preference differed between subjects. In total the preferences from 30 (23) of 38 subjects were predicted successfully but from different regions in PFC in case of the within (across) conditions.

Classification across time: Because of the individual differences in regions being predictive for preferences, we tested consistency across time. In total the preferences from 27 (28) of 38 subjects were predicted successfully from different regions in PFC in case of the within (across) condition with accuracies ranging from 58% to 63%. The individually predictive regions at the second time point were to 69 % consistent with the first time point.

Conclusions:
Preferences for foods belonging to identical or different categories can be predicted reliable across time from subregions in PFC in most subjects. But, there seem to be important inter-individual differences regarding the specific subregions in PFC being responsible for those predictions.

Stress exposure decreases cooperative decision-making behavior

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Objective: Cooperation plays a central role in human society; however, the way that aversive emotional states, such as stress, influence such behavior remains unknown. Stress has been shown to engender a reliance on habitual forms of behavior, suggesting that stress may increase cooperation, which has been described as an automatic or reflexive response. Alternately, the aversive nature of stress exposure may promote self-preservation, resulting in more selfish (i.e., less cooperative) behavior. Here, we sought to distinguish these possibilities by inducing acute stress in individuals before they completed a classic behavioral economic game that measures cooperative decision-making behavior.

Method: In two separate studies, participants first underwent a stress induction task (i.e., cold pressor), which has been shown to reliably elicit autonomic and neuroendocrine responses to stress, or a matched control task. Participants then completed 36 trials of either the Prisoner's Dilemma (PD) game, in which they could either cooperate with a partner for lower monetary gain or betray them for higher monetary gain, or a matched non-social lottery game. In Study 1, participants played a one-shot version of the PD game in which a new partner was encountered on every trial. In Study 2, participants played an iterative version of the game in which they played with the same partner on each trial. Salivary cortisol was collected throughout the experiment to confirm the efficacy of the stress manipulation.

Results: As expected, our stress induction successfully increased cortisol responses in the stress group only. In each study, stress exposure significantly reduced prosocial behavior by decreasing the proportion of trials that participants chose to cooperate with their partners, and instead increased their propensity to betray their partners for more money. This tendency was found irrespective of whether subjects played a one-shot version of the game (Study 1), which tends to promote lower cooperation, or an iterative version of the game (Study 2), which tends to promote cooperative choices since subjects repeatedly play with the same partner. No differences were found between groups for the lottery (control) task in either study.

Conclusions: Exposure to mild forms of stress, such as those that may be encountered in everyday life, can lead to marked reductions in decisions to cooperate, suggesting that this form of prosocial behavior is highly sensitive to changes in affective states. By studying the effect of stress on cooperative decision-making, this work promises to situate our understanding of prosociality in a broader framework that reflects the influence of real-world conditions of stress exposure.

Acknowledgements:
This study was funded by the NIH, grant # R01AG039283.

The Neural Mechanism of the Zero-Price Effect

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Objective: Deciding whether or not to purchase a product relies on a cost-benefit computation: comparing the utility derived from the product to the disutility of having to pay for it. In this study, we investigate the neural correlates of pricing. As a special case, we look at the zero-price effect, a valuation bias, where a product triggers an abnormally high demand and inconsistency in consumers' preferences because it is available for free. Using a binary choice task in an fMRI session, we examine the underlying effect of evaluating a product at various prices and at the same time we investigate this valuation bias.

Methods: 40 participants (20 females) took part in this experiment. In a first session, participants viewed a set of 225 consumer goods and indicated their willingness to pay (WTP) for each of the products. Based on these WTPs we constructed binary pairs of stimuli: a "target" product and an "other" product (with a slightly higher WTP). This was done to ensure there is no preference for the "target" item. In a second experimental session participants performed a choice task while in the MRI scanner. On each trial, they were presented with a choice between the "target" and the "other" product, each associated with a certain price. The "target" item was sold for five prices: €0, €2, €4, €6 and a bonus price of + €2 (i.e. the participant received the product, plus an additional €2). The "other" product was priced as the "target" price plus the absolute difference in WTP values. The task was fully incentivized: out of 150 choices, one was randomly selected and paid out at the end of the experiment.

Results: Behavioral results confirmed the zero price effect: in the €0 condition participants chose the "target" item significantly more often than chance. Importantly, there was no increase in choices for the "target" item in the bonus (+ €2) condition compared to the €0 condition. This indicates that choices were not driven by the desire to maximize ones' outcome. The number of choices for "target" items in the remaining conditions (€2, €4, €6) was not different from choices for the "other" items. With respect to the fMRI data, we found that caudate negatively correlated with the price of the product: the lower the price, the higher the caudate activity.

Conclusions: We show that zero-priced products are indeed chosen more often over more valued, but higher priced alternatives. Our findings contribute to the understanding the neural mechanism behind price processing.

Interrupt the Impulse: Lateral prefrontal cortex function is necessary for optimal choice in the Prisoner's Dilemma

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Objective: Previous functional imaging studies investigated the neural basis of strategic decision making in the prisoner's dilemma. They reported a correlation between cooperative behavior and dorsolateral prefrontal cortex (DLPFC) activity; however, the precise function of the DLPFC in establishing cooperation remained unclear so far. The present study investigated the causal role of the DLPFC in an iterative prisoner's dilemma game (PDG) with transcranial magnetic stimulation (TMS).

Methods: We used an offline TMS design: 56 participants were first stimulated for 8 minutes at 1 Hz at either the left PFC, right PFC, vertex (TMS control site) or not stimulated (no TMS control). Then they played a total of 48 rounds of an iterated PDG against virtual opponents, which were programmed to play a tit-for-tat strategy 80% of the time. The participants were instructed which trial outcomes led to which money distributions and were told to try to gain as much money as possible. However, they were not briefed on which the best strategy was to achieve this goal.

Results: We discovered that disrupting the left or right PFC with TMS decreased cooperation rates in comparison to control conditions, with this effect being most pronounced when the partner had betrayed previously.

Conclusions: The left and right PFC seem to be both necessary for making optimal choices in a prisoner's dilemma game (PDG). The perfect strategy in the PDG is a generous tit-for-tat strategy, which means that betrayal should not immediately be answered with betrayal on the next trial as this will lead to unwanted mutual betrayal situations. In general, this finding fits well into previous research about the PFCs involvement in impulse control. A precondition of playing a generous tit-for-tat strategy may be the ability to suppress the impulse to reciprocate following a partner's betrayal. DLPFC TMS may have inhibited subjects' impulse control, resulting in the observed reduced cooperation.

Acknowledgements:
The authors declare no competing financial interests.

The Dynamics of Continuous Self Control

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Objective: In recent years, substantial advances have been made in understanding the behavioral and neural bases of self control in discrete choices (e.g. a choice to order healthy or unhealthy food off a menu). However, we must often use self control over longer timescales, in a continuous fashion (e.g. resisting eating cake in your kitchen all afternoon). Little is known about the processes supporting continuous self control, let alone their temporal dynamics, but clues may come from a recent movement toward "rational self control" models. Such models reconceptualize self control as trading off multiple sources of utility under constraints (like limited attentional capacity, or limited time). The question of how self control is exercised then becomes a matter of identifying utility sources, their characteristics, and quantifying the constraints involved.

Methods: Twenty-seven heterosexual males completed a novel paradigm with known temporal and reward structures pitting a boring, but monetarily rewarding task against distracting images for 60 uninterrupted minutes. Half of the screen had a white circle with a "clock hand" that ticked in roughly 1/100 increments every second. Rarely ($p = 0.01$), the hand would move twice as far ($\sim 2/100^{th}$). Participants received $1 for every correctly identified double-sized movement, but lost $1 for every false alarm. The other half of the screen displayed the subset of IAPS images rated positively by males, with images changing every 1 or 2 seconds (synchronized with clock hand movements). We recorded eye tracking data throughout the session, allowing us to examine when participants were "on-task" (watching the clock hand) vs. "off-task" (looking anywhere else), as a function of clock hand movements, image content, and image changes.

Results: We created a computational model based on the optimal tradeoff between the known expected utility of clock hand movements and the fitted "consumption utility" of the images, under constraints including the subjective estimation of the passage of time, modeled with a linear ballistic accumulator. The model fit gaze behavior well, and allowed the inference, from gaze alone, of the consumption utility of a given image for a given participant, as well as changes in that value over time. Critically, consumption utility was not reducible to ratings of valence or arousal and was separable from visual salience.

Conclusions: This combination of a novel task and computational models of how limited agents seek and consume utility over time holds the potential to provide new insights into the processes underlying continuous self control in both healthy and clinically-disordered populations.

Acknowledgments: Thanks to Antonio Rangel for contributions to design and analysis.

Evidence of Quantization in Intertemporal Decision Making

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Objective: Quantization[1] divides a continuous quantity into a discrete (finite) number of small parts (steps). Recently, evidence of a quantized representation of probability[2] was reported; a quantized representation of value was also theorized[3]. We hypothesize that intertemporal choices are quantized as well: people may treat (or discount) 16 days indifferently to 16.5 days. To test this, we analyzed an intertemporal task using a novel quantized hyperbolic discounting model.

Methods: On each trial, a subject chose between 2 options: $40 now, or $X in D days. $X is capped at $100 while D ranges from 1 to 327. There were 204 trials. Subjects were paid $20 and a bonus corresponding to the option chosen on a single randomly drawn trial. The bonus was paid using a debit card at the appropriate delay date. 20 subjects performed the task. Subjects were pre-screened with a similar task in order to customize the stimuli range (i.e. $X, D) to each subject. Our quantized analysis here is a re-examination of the behavioral data previously[4] collected for an fMRI study.

Results: Conventionally, intertemporal choices are modeled using the continuous hyperbolic discounting model $SV = \frac{A}{1+kD}$. We fitted our data using a quantized hyperbolic discounting model $Q_n\left[\frac{SV}{A}\right] = Q_n\left[\frac{1}{1+kD}\right]$, where there are 2^n number of steps. The continuous model is simply a quantized model with an infinite number of steps. We found that 9/20 subjects were best fit to 5-bit quantized models (i.e. $2^5 = 32$ steps). We performed bootstrap simulations to test whether this quantized result could have been confounded with a continuous population (null hypothesis). Using a G test statistic, we rejected the null at $p < .001$. As a check, we also performed the standard Chi-square test, which rejected the null at $p < .0001$. Finally, using nested hypothesis testing, we found that 17/20 subjects were best fit to 5-bit quantized models.

Conclusions: Our results are intuitive – people categorize (or chunk) time. While continuous models are convenient for analyzing experiment data, we should be open to the real possibility that decisions are quantized.

Acknowledgements: Grants EY019889 (NIH) & R01 DA029149 (NIH/NIDA)

[1] Gray, R.M. & Neuhoff, D.L. (1998). Quantization. *IEEE Transactions on Information Theory*, 44(6), 2325-2382.
[2] Tee, J., Zhang, H. & Maloney, L.T. (2013). Evidence of quantization in human decision making. *Society for Neuroeconomics Annual Meeting*, Lausanne, Switzerland.
[3] Woodford, M. (2014). Psychophysical aspects of choice behavior. *The Kavli Foundation Social & Decision Science Workshop*, Miami.
[4] Cox, K.M. & Kable, J.W. (2014). BOLD subjective value signals exhibit robust range adaptation. *The Journal of Neuroscience*, 34(69):16533-16543.

Dissecting charitable giving: Empathy, mentalizing and reorienting of attention differentially predict generous donation decisions

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Objective: A growing body of evidence suggests that social processes related to understanding others thoughts and feeling states (i.e., mentalizing and empathy) might contribute to the substantial variance in people's altruistic behavior. Teasing apart the contributions of these interrelated – but conceptually distinct – processes, however, is challenging. Using an fMRI donation task together with multivariate decoding techniques, we aimed to delineate sub-processes underlying altruistic decision-making and to link them to dissociable neural computations.

Methods: 32 healthy participants performed an fMRI donation task and a behavioral post-test in which participants reported their empathy and mentalizing during previous donation choices. They also participated in a separate empathy and mentalizing fMRI task (without donation choices) and an fMRI attention task (Posner).

Results: We identified 3 distinct psychological bases for generous decision-making (empathy, mentalizing, attentional shifts) and their neural substrates:

Neural responses in the anterior insula (AI) (but not the temporo-parietal junction, TPJ) encoded trial-wise empathic responses for beneficiaries, while the TPJ (but not the AI) predicted the degree of mentalizing. We also identified the relative influence of both processes across individuals: Participants whose donation behavior was heavily influenced by affective empathy exhibited higher predictive accuracies for generosity in the AI. In contrast, increased importance of cognitive mentalizing for donation behavior correlated with improved neural predictions of generous giving in the TPJ. Interestingly, functional brain data obtained during a separate empathy and mentalizing task predicted the degree to which participants relied on both processes during donations. This suggests that the input of empathy and mentalizing into donation decisions might be related to participants' general propensity to engage in these processes in the face of another's suffering.

Finally, using independent data from an attention task, we found evidence for shared neural code for reorientation of attention and generous donations in the posterior superior temporal sulcus (but not in TPJ or AI). This result suggests contributions of domain-general attention shifts to (socially relevant) stimuli for generous behavior.

Conclusions: Our findings demonstrate the utility of multivariate decoding techniques to delineate processes underlying charitable giving behavior and to identify their relative influence in different individuals. These findings inform us about discrete routes via which altruistic behavior can be enhanced.

Characterizing human decision-making in combinatorial games

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Objective: Decision-making tasks such as negotiation, career planning, competitive sports, and military strategy all involve long sequences of decisions with multiple options at each step, leading to a combinatorial explosion of the decision tree. To make such decisions tractable, people must prune the decision tree. We investigate how people do this in a controlled laboratory setting.

Methods: We collected behavioral data from human subjects playing a variant of tic-tac-toe – a full-information, deterministic, two-player, adversarial game. Human subjects played against each other (Exp 1), played against AI agents of different strengths (Exp 2 and 3, Cond 1), chose between two alternatives in a given position (Exp 2 and 3, Cond 2), or evaluated a position (Exp 2 Cond 3). Exp 3 differed from Exp 2 in that we tracked subjects' eye movements.

In our main models, players use a set of features and weights to assign values to board positions, and mentally simulate a reduced decision tree using one of two AI-inspired algorithms, best-first search (BFS) or depth-first search (DFS). We introduce variability through value noise, stochastic feature dropping, and a lapse rate. Alternative models are a mixture model of optimal and random play (OptRand) and a model in which players do not build a decision tree (NoTree).

Results: Across all experiments, we found that BFS and DFS fit the data about equally well and much better than OptRand and NoTree; parameter estimates are more plausible for BFS. All noise sources are critical for a good fit. The BFS and DFS model fitted to subjects' play against AI agents in Exp 2 predicted individual-move 2AFC choices and evaluations above chance. In Exp 3, we found that the number of visits to a square during the tree search process in the fitted BFS and DFS models is a strong predictor of the amount of attention subjects place on a square, as measured by their eye movements.

Conclusions: Our results demonstrate that 1) people utilize decision trees in combinatorial games; 2) a feature-based value function combined with the best-first search algorithm is a plausible, generalizable description of human play; 3) people's eye movements are correlated to their tree search process.

Acknowledgments:
This study was funded by the NSF, Grant #IIS-1344256

Observational learning and its influence on the observer's learning rate

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Abstract

Objective: We study experimentally the influence that observing choices of others has on subjects' own learning rate and ability to understand the uncertain environment.

Methods: In a very simple design, subjects make choices in a 2-armed bandit problem. They observe two pictures on the screen and choose between them in multiple trials. The probabilities of getting a reward from each option follow a random walk throughout the whole experiment. Sometimes, before making their choice, subjects also observe the choice of one of the two other subjects (but not the outcomes that others have obtained). Subjects are aware that the others choose in the same environment as they do. The other subjects (actually computer simulated sequences of choices) have different learning rates, which results in different choice patterns. One other subject switches often between actions (switcher) while another chooses the same option for prolonged periods of time (non-switcher). We are currently testing the adjacent hypotheses in an fMRI study with the same design.

Results: We find differential influence of the observations of others on the personal success in learning the environment. Subjects are biased to imitate non-switchers which leads to the increase in the performance of slow learners and decrease in the performance of fast learners. We estimate personal learning rates and exploration parameters and find that fast learners seem to decrease their learning rate when observing others and slow learners increase it. In addition there is a strong bias to follow non-switchers, which might be sub-optimal in the given environment.

Conclusions: We show that observing others can have opposite effects on people with different learning skills. Observational learning has a bias towards imitating non-switchers, which can be beneficial to some learners, but detrimental to others.

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Sense of choice during motivated encoding represented in reward processing region

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Objective: To investigate brain mechanisms mediated by human volition or sense of agency we examined the role of sense of choice (feeling of having choice option) in pursuit of monetary reward. To explore how sense of choice plays a role in motivated memory help us to understand the interaction of intrinsic motivation and explicit reward and its' influence on memory.

Methods: During fMRI scanning, 16 participants deliberately encoded words with or without sense of choice over a card behind which has two words and the amount of tentative monetary rewards. In the sense of choice condition, they could choose a card that they want to flip but in the loss of choice condition they obligatorily had to flip what a computer pointed out. Two words in a card were tested separately in the following recognition test and we presented feedback (correct or incorrect) for each retrieval response. In one condition we gave reward or punishment depending on their performance but in another condition there was only cognitive feedback without monetary gain or loss. In the other condition, we gave them a cue that who had flipped the word during retrieval.

Results: Behavioral results showed interaction of choice and risk. Retrieval performance was better in the sense of choice condition than in the loss of choice condition when there was only cognitive feedback, however, this effect was vanished with a risk to gain or lose money. When with a retrieval cue, they recovered more memory in the loss of choice condition than in the sense of choice condition. In the sense of choice versus loss of choice contrast, neural data from the card-flipping task showed that activation in left HC, bilateral caudate and OFC were evoked while participants were noticed whether they would have a choice or not. Activation in bilateral VTA, insula, SMA and precuneus were evoked during period of encoding with card flipping. Neural data from retrieval sessions showed that bilateral HC and VTA were activated when there was only cognitive feedback and right caudate was activated when there was explicit monetary reward in the aforementioned contrast. Left OFC was activated when participants retrieved with a retrieval cue and bilateral VTA was activated when they were given monetary outcome after the retrieval.

Conclusions: This research suggest that, during motivated encoding , intrinsic motivation of sense of choice recruits the caudate and VTA known as reward processing, hippocampus contributing to memory formation, and SMA usually reported with sense of agency. Behaviorally the benefit of sense of choice could be covered up with explicit monetary risk, supporting complementary relationship of intrinsic and extrinsic motivation.

Acknowledgements:
This research was supported by the Basic Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and Future Planning (#2015-R1A2A2A04006136).

Adaptive value coding: Temporal influences on choice mediated by divisive normalization in rhesus monkey

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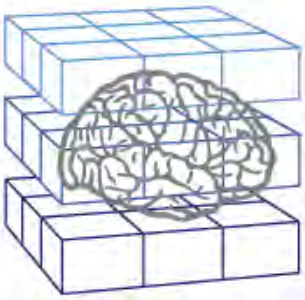
Any organism has to react and adapt to a constantly changing environment. Its neuronal system is thus confronted with the task of encoding a broad range of sensory information efficiently within the finite constraints of its coding capacity. This problem is widely believed to explain temporal adaptation and spatial normalization in sensory systems. Recent work has demonstrated that temporal adaptation occurs in reward-processing and decision-related brain areas, but the computational mechanisms and behavioral consequences of this temporal adaptation have remained largely unknown.

Here, we present data from a saccadic choice task. Trained monkeys were offered a choice between two options differing in reward magnitude and juice type. Block of trials were presented which were composed of a mixture of “adaptor trials” and “measurement trials”. In measurement trials, fixed in structure across all blocks, monkey were asked to choose between an unvarying reference reward (fixed reward magnitude and juice type) and one of 5 variable rewards. These responses allowed us to plot the monkey’s probability of choosing the reference reward as a function of the magnitude of the variable reward; exposing a “*choice curve”*. What we systematically varied across blocks was the structure of the adaptor trials. We then examined the effects of the standard deviation of adaptor variability on the slopes of these choice curves.

We attempted to account for the effects of adaptor variability on choice behavior using a model of adaptive value coding based on the dynamic normalization models we have previously explored. Our current model implements two cascaded divisive-normalization networks which we refer to euphemistically as OFC and LIP. Adaptation is implemented via divisive normalization, a canonical neural computation widely reported in sensory processing, in both networks. The time constants of the networks, however, differ by several orders of magnitude (with OFC being much slower) and allows the OFC network to effectively adapt the sensitivity of the LIP network.

Our behavioral and simulation results demonstrate that the temporal value context significantly influences monkey choice behavior and that the temporal dynamics of our model can account for these changes. The findings suggest that divisive normalization, may underlie adaptive value coding in decision-making areas and shape behavioral choices accordingly. Single unit recordings from real monkey OFC will relate neuronal dynamics to behavioral and model dynamics in a future step.



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Session II
Social preferences and strategic interactions

Low frequency rTMS to monkey STS moderates neuronal sensitivity to social reward

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The superior temporal sulcus (STS) region of cortex contributes to various aspects of social cognition, including face perception, biological motion detection, joint attention, empathy, and theory-of-mind. Recent brain imaging studies have also implicated this area in social decision-making. The precise neuronal mechanisms mediating STS contributions to social decisions remain unknown. To answer this question, we used a combination of repetitive transcranial magnetic stimulation (rTMS) to STS and simultaneous neuronal recordings in the same area in monkeys performing a social reward-allocation task (Chang et al., 2011, 2012, 2013). Monkeys chose to allocate juice rewards to self, another monkey, both, or no one. Consistent with our prior published studies, monkeys preferred to reward the recipient monkey over no one, but preferred to reward self over both monkeys. Single and multi units in the middle STS responded strongly during the choice commitment and reward-outcome phases of the task. Moreover, firing rates varied systematically with the social context of decision, responding most strongly to "both" and "self" trials and significantly less to "other" and "none" trials. Importantly, firing rates were significantly higher when monkeys chose "other" over "none," and these preferences were magnified in a second condition that cued different magnitudes of reward. Critically, 10 minutes of low-frequency (1Hz) rTMS - a stimulation regime thought to suppress neuronal activity - to the STS abolished social preferences expressed behaviorally and simultaneous neurophysiological distinctions between social reward outcomes. Sham stimulation had no impact on social preferences or neurophysiological activity. Together, these findings suggest STS neurons signal predicted and experienced social reward outcomes and that these signals contribute directly to social decisions. Our data also demonstrate that low-frequency rTMS impairs behavior by disrupting neurophysiological activity at the site of stimulation.

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Basolateral amygdala lesions abolish mutual reward preference in rats

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Objective: In a recent study, we demonstrated that rats prefer mutual rewards in a rodent Prosocial Choice Task (PCT). One likely candidate region necessary for driving social learning is the amygdala. We therefore asked if the basolateral amygdala (BLA) plays a crucial role in the expression of mutual reward preference.

Methods: Pairs of two rats, an actor and a partner rat, performed the PCT. Actor rats received bilateral excitotoxic (n = 12) or sham lesions (n = 10) targeting the BLA and were subsequently tested in the PCT where they could decide between rewarding ("Both Reward" BR) or not rewarding their partner rat ("Own Reward" OR), either choice yielding identical reward for them. To manipulate the social context and control for secondary reinforcement sources, actor rats were paired with either a partner rat (partner condition) or with an inanimate rat toy (toy condition).

Results: Sham-operated animals revealed a significant preference for the BR option in the partner condition, but not in the toy condition. BLA-lesioned animals exhibited significantly lower BR preferences than the sham group in the partner but not in the toy condition, suggesting that BLA is required for the acquisition and expression of mutual reward preferences. Critically, in a reward magnitude discrimination task in the same experimental setup, both sham-operated and BLA-lesioned animals preferred large over small rewards, suggesting that BLA lesion effects were restricted to decision making in social contexts, leaving self-oriented behavior unaffected.

Conclusions: These results suggest that BLA is necessary for acquiring and expressing mutual reward preferences. Because the lesion effects were restricted to social contexts, we suggest that the BLA may be important for increasing an animal's sensitivity to the emotional value of social information, and therefore drive social learning.

Acknowledgments: The study was supported by the Deutsche Forschungsgemeinschaft (DFG), grant n° KA2675 / 5-1 to TK. MvW was supported by the Volkswagen Stiftung "Freigeist" fellowship, AZ 88216.

Neural Adaptation Mediates Escalation in Dishonesty

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Objective: Neural adaptation is a change over time in the responsiveness of neurons to a stimulus or situation. It has been extensively studied in sensory circuits, yet its consequences to social behaviour and choice is relatively unknown. Here we demonstrate how this fundamental property of the human brain explains a phenomenon with overreaching societal impact – escalation of corrupt behaviour.

Methods: We combined brain imaging with a behavioural task in which individuals can repeatedly and voluntarily act dishonestly without being required to admit so. Specifically, on each trial participants advised a second participant regarding the amount of British Pennies in a glass jar. On some trials dishonesty was advantageous for the participant, while on others honesty was. The specific task structure enabled us to estimate the amount by which a participant was lying on each and every trial.

Results: Under this controlled laboratory setting we demonstrate that the extent to which participants engaged in dishonesty grows over time. Using fMRI we show that BOLD signal reduction in the amygdala is sensitive to the history of dishonest choices. Critically, we provide evidence that such adaptation acts as a teaching signal, predicting subsequent escalations of corruption.

Conclusions: Real world examples in which corruption escalates are plentiful; from scientific misconduct to financial fraud, plagiarism and infidelity. Our findings suggest that despite being trivial at the outset, engagement in small immoral acts can trigger a biological process that generates a "slippery slope": what begins as small acts escalate into larger instances with harmful consequences for those at the receiving end.

Acknowledgements:
This research was supported by a Wellcome Trust Career Development Fellowship to T. Sharot and a UCL Impact Award to N. Garrett.

A causal account of the neural computations in TPJ subserving strategic choice in competitive social interactions

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Objective: In competitive interactions, humans can anticipate the influence of their own choices on their opponent and update their strategy accordingly. On the neurobiological level, such influence update signal has been found to correlate with neural activity in parts of the superior temporal sulcus (STS) (Hampton, Bossaerts, & O'Doherty, 2008), a region belonging to the temporo-parietal junction (TPJ) and commonly thought to be involved in mentalizing. Here we employ continuous theta-burst stimulation (cTBS) to test whether a functionally intact rTPJ is necessary for incorporating second-order beliefs into choice, which we combined with functional magnetic resonance imagery (fMRI) to characterize the neurobiological pathways responsible for behavioral change.

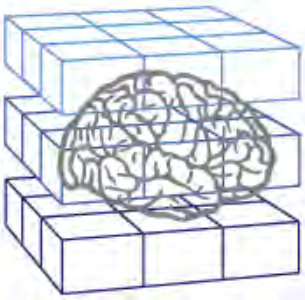
Methods: 120 healthy volunteers participated in the experiment. Sixty participants were scanned while playing a repeated inspection game with monetary rewards in the role of Employee, whereas the other 60 took the role of the Employer outside the scanner. The choice data was fitted with different computational models quantifying reinforcement learning, fictitious play, and influence learning. Model parameters were estimated through a hierarchical Bayesian approach and used to derive subject-specific regressors for general–linear-model analysis of the neuroimaging data.

Results: We show that disrupting neural excitability in the rTPJ leads to a deficit in the ability to incorporate second-order beliefs into choice. On the neurobiological level, this behavioral deficit was accompanied by a corresponding decrease in the representation of the influence update in rTPJ and alterations in value coding in vmPFC. Moreover, functional connectivity analysis revealed that cTBS lead to a reduction in connectivity of rTPJ with dmPFC and vmPFC, indicative of perturbations in the estimation of the influence update and its integration into value.

Conclusions: Disruption of rTPJ produced behavioral changes that were precisely aligned with the theoretical predictions of the computational model, providing evidence that the influence update algorithm validly characterizes the aggregate output of the computations performed by this region. The observed failure to incorporate second-order beliefs into choice means disregarding the opponent's learning, thereby rendering behavior essentially non-strategic. Thus, our results provide novel evidence that strategic choice crucially relies the neural computations instantiated in rTPJ and its connectivity with vMPFC and dmPFC, two key nodes of the valuation and mentalizing networks.

Reference:

Hampton, A. N., Bossaerts, P., & O'Doherty, J. P. (2008). Neural correlates of mentalizing-related computations during strategic interactions in humans. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(18), 6741–6746. http://doi.org/10.1073/pnas.0711099105



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Session III
Valuation, risk and time preference

Expected Subjective Value Theory: A Representation of Decision in Time Under Risk

Agnieszka Tymula[1] and Paul Glimcher[2]

Over the past few years there has been growing interest in the notion that a representation involving divisive normalization (a canonical neural computation in sensory systems) normatively encodes option value in the brain. The divisive normalization algorithm has been shown to rationalize behaviors previously labeled as anomalous in economic theory, including violations of the independence of irrelevant alternatives (Louie, 2013). There is growing understanding that such anomalies in decision-making are in fact a result of an efficient value coding by a system that has limited neural resources (Glimcher, 2010; Woodford, 2012, 2014; Hunt et al, 2014). The implications of the efficient value coding through the divisive normalization algorithm

$$v(x_{i,t}) = \frac{x_{i,t}^{\beta}}{x_{i,t}^{\beta} + (\sum_{0}^{t-1} \delta(t) x_{i,t})^{\beta}} + \varepsilon$$

have, however, not yet been carefully considered with respect to the decision making under risk.

This paper presents a near-normative model of choice under risk that incorporates neurobiological constraints and costs into a traditional economic framework via divisive normalization. It yields an expected utility-like model that captures many of the behavioral phenomena around which prospect theory was built, but without recourse to a completely descriptive approach. The model defines the reference point as an adaptive mechanism that optimizes precision at expectation. It captures the same 'representative agent' choice behavior as prospect theory but unlike prospect theory also captures single agent behavior. It accounts for such behavioral phenomena as lack of a reflection effects on the individual level and the non-independence of loss aversion and risk seeking in individuals. It makes novel predictions about how risk attitudes and loss aversion depend on the history of experienced rewards - their timing, value and variation – in a more normative fashion. It also captures heterogeneity in individual preferences related to individual differences in neural constraints (such as those present in aging or illness), thus allowing us to unify numerous previously observed associations between a host of brain changing variables and risk attitudes and loss aversion.

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Intertemporal Choice and Valuation are Influenced by the Attraction Effect

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Objective: Classical economic theory contends that the utility of a choice option should be independent of other alternatives, and dominant intertemporal choice models (including exponential and hyperbolic discounting) adhere to this principle. However, research on multi-attribute decision making has shown that people are attracted toward specific options if asymmetrically dominated (i.e., similar but clearly inferior) alternatives are added to the choice set. We hypothesized that this attraction effect biases intertemporal choices as well as the evaluation of outcomes by means of the reward prediction error.

Methods: A first group of $N_1 = 21$ participants repeatedly chose between two or three intertemporal choice options characterized by different rewards and delays. In some three-option trials, a third *decoy* option was clearly inferior to a *target* option but not to a *competitor* option. *Targets* and *competitors* were matched with respect to subjective value (based on modeling the two-options trials with hyperbolic discounting). A second group of $N_2 = 29$ participants conducted a corresponding lottery task while being scanned with fMRI. In this lottery task, participants were first shown three possible outcomes and then told which of them would be paid out.

Results: Consistent with the attraction effect, participants of the first group showed a clear preference for *targets* over *competitors* ($p < .001$). Similarly, participants of the second group rated *target*-outcomes as being more pleasant than *competitor*-outcomes ($p = .003$). The reward prediction error in the lottery task (i.e., the value difference between the actual and the three possible outcomes) was associated with fMRI signals in the nucleus accumbens (NAcc) ($p < .001$; small-volume corrected). Across participants, higher NAcc activation for *targets* vs. *competitors* was correlated with higher pleasantness ratings for *targets* vs. *competitors* ($p = .013$; small-volume corrected).

Conclusions: Our results challenge existing theories of intertemporal choice as well as the view that subjective values can be measured in a context-free manner. Moreover, a liability of the reward prediction error to the attraction effect has important implications for reinforcement learning theory.

Acknowledgements:
This study was funded by the Swiss National Science Foundation (SNSF), grant # 100014_153616.

Category-independent value and salience signals in the human brain

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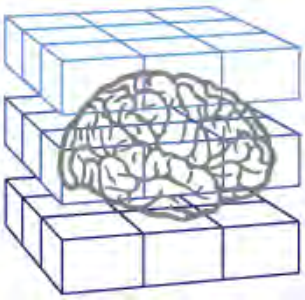
Objective: The ability to compute and assign values in a common scale to predictive cues and outcomes across different categories is essential for value-based decision making. An extensive literature in decision neuroscience has focused on the neural mechanisms of value computations, and a 'valuation system' in the brain has emerged from these studies. Few studies, however, included both rewards and punishments in their design to disentangle value and salience signals, which are highly correlated in either the positive or the negative domain alone. Even fewer studies assessed the degree to which those signals are category-dependent. Here we present evidence from a human fMRI study for category-independent value and salience signals in different brain regions.

Methods: 18 healthy participants were scanned while performing the reward and punishment task. In this task, participants were presented with cues that predicted the probabilistic delivery of different types of outcomes. Four outcome categories were used: monetary gains and losses, viewing of pleasant faces, and electric shocks. Four magnitude or intensity levels were used for each outcome type, so that a wide range of value and salience were experienced by the participants. On third of the trials outcome was provided after a delay period. Pleasantness ratings were collected both at the cue (anticipation) phase and at the outcome (receipt) phase, and trial-by-trial value and saliency were estimated from these ratings. The fMRI data was analyzed using both general linear models (GLM) and representational similarity analysis (RSA).

Results: In the cue phase, blood oxygen level-dependent signals in the orbitofrontal cortex and the posterior parietal cortex monotonically increased from extreme negative to extreme positive values, consistent with a linear value signal. The rostral anterior cingulate cortex (rACC), and the anterior insula showed a U-shaped salience-like activity profile, in which signals increased for anticipation of both increasing positive and increasing negative outcomes. Finally, the striatum encoded both value and salience signals. Importantly, the observed signals were on a unified scale that applied to different categories. Similar analysis also revealed that, in the outcome phase, the vmPFC, striatum, and the posterior cingulate cortex (PCC) represented value and the rACC represented salience, both in a category-independent manner. In a complementary set of multivariate analyses we identified a value-salience hybrid model which outperformed other candidate models in explaining the activity patterns in the vmPFC.

Conclusions: These results dissociate representations of category-independent value and salience signals in the human brain. Furthermore, based on results from RSA we propose a computational model in which the reliability of value representations is modulated by salience.

Acknowledgements:
This study was partially funded by NIH/NIMH grant number R21MH102634 and NCATS CTSA grant number UL1 TR000142.



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Session IV
Self control and well-being

Dietary self-regulation is linked to individual differences in serum leptin and delay discounting for food but not money in lean participants

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Objective: When making dietary choices, consumers often face a trade-off between different attributes serving different dietary goals. For instance, choosing between a fresh apple and a succulent cake appears to depend on the trade-off between the long-term health and the short-term sensory reward of each option. Previous studies have shown that a consumer's ability to down-regulate food cravings is facilitated by focusing on the long-term health attributes of food. Such down-regulation correlates with decreased neural activity in the vmPFC and is modulated by activity in the dlPFC. The goal of this research is to link consumer's down-regulation abilities to individual differences in (1) energy hormone levels that regulate one's hunger state and are related to dopaminergic functioning (i.e., serum leptin) and (2) impatience as indicated by behavioral measures of delay discounting for food and money. We hypothesized that (1) increased serum leptin levels and (2) lower impatience measured in a delay discounting task correlates with better down-regulation abilities. We also explored the question whether general impatience for food and for other, secondary rewards (i.e., money) can be linked to down-regulation or whether such effects are specific to responses to food.

Methods: We scanned 31 healthy, lean female participants' brains using fMRI while they performed two different tasks: (1) a validated self-regulation task during which they had to assign stimulus values (SV) to food considering their natural preferences (control condition, NC), the long-term health benefits (health condition, HC) or the short-term taste benefits (taste condition, TC) of the foods for choice; (2) a validated delay-discounting task for rewarding food and money to asses participant's impatience. We varied the size of smaller sooner rewards (SSR=8-35€/chocolates matched in economic value) and larger later rewards (LLR=9-42€/chocolates matched in economic value) available two weeks later than the SSR. We also varied whether the SSR were available immediately ("now condition") or at later point in time ("not now condition"). Serum leptin levels were assessed after 12h of overnight fasting in 20 participants.

Results: We first replicated previous findings showing that when participants concentrated on the long-term health reward of food they attributed lower SV's to the food ($t(30)=-4.1$, $p<0.001$) and showed decreased ventromedial prefrontal cortex responses to SV ($t(30)=-2.8$, $p<0.01$) compared to the control condition. We then investigated the link to serum leptin levels corrected for body fat mass and found that behavioral and neural down-valuation of food during the HC negatively correlated to serum leptin levels (behavioral delta: $r=-0.44$, 95 % CI: -0.37 – 0.38; vmPFC delta: $r=-0.46$, 95 % CI: -0.38 – 0.38). Next, we investigated the link between down-regulation abilities and impatience. Behavioral findings show that impatience, assessed by the % LLR choices, was greater for food than for money (two-way ANOVA $F(1,119) = 4.1$, $p = 0.04$). Impatience was lower in the "not now" vs. "now" condition (two-way ANOVA $F(1,119) = 4.8$, $p = 0.03$) replicating the well-known immediacy effect. Correlations between % of LLR choices during the 'not-now' condition and regulatory success was significant for food (rho = -0.46; 95% CI: -0.30 – 0.29), but not for money (rho = -0.24; 95 % CI: -0.31 – 0.31).

Conclusions: Our current set of results provide first evidence that successful dietary down-regulation of food cravings can be linked to (1) increased serum leptin concentrations and (2) reduced impatience as indicated by behavioral measures of delay discounting for food but not for money. Our findings provide novel insights into the psychobiological mechanisms of self-control that are important for a better understanding of dietary choices in health and disease (i. e., obesity). We are currently extending our first findings by further analysis of the brain-level data during the delay-discounting task that will be finished by the time of the conference.

Acknowledgements: This study was funded by the ICAN "Brain-Gut" grant, the Clinical Research Contract (Microbaria) and the Sorbonne University Convergence grant "GutBrainSC". We thank Valerie Godefroy, Agathe Arlotti, Cendri Hutcherson, Richard Levy and the staff of the ICM brain-imaging center of the Pitié-Salpêtrière hospital for their support.

Self-control signals in medial frontal cortex of monkeys during a temptation task

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Objective: Self-control is the ability to resist rewards that are tempting, but lead to suboptimal long-term outcomes. It has been suggested that the intertemporal choice task can be used as a measure of self-control, because the task requires subjects to choose between a smaller, sooner reward (S) and a larger, later reward (L). However, it has been difficult to behaviorally estimate self-control in this task, because self-control is required only for a short period just before a choice is made and there are too many other factors that affect the choices of the subjects. Therefore, we developed a new task that provides a measure of resistance to persistent temptation and trained monkey subjects with the new temptation task.

Methods: In every trial, two annulus-shaped targets (S and L) were presented after a fixation period. Each annulus had a colored section, whose length and color indicated the delay and amount of rewards, respectively. The subjects had to make a saccade to one of the targets and fixate it, until they received the indicated reward amount. In no-temptation trials, the unchosen target disappeared upon the choice of either target. However, in temptation trials, the unchosen target did not disappear and the subjects were allowed to change their initial choice as long as the time of the chosen target did not run out. Since temptation and no-temptation trials were randomly interleaved with no cue, the subjects' initial choice functions were identical in both conditions and therefore indicated their true preferences regardless of the conditions. Nevertheless, the subjects sometimes switched targets in temptation trials. This typically involved a switch from an initial delayed L target to an immediate S target (L-S switch). The opposite switch (S-L switch) occurred almost never. These results indicate that an L-S switch is the result of a failure in resisting temptation of the immediate reward and not the correction of a mistake in the initial choice.

Results: To investigate the neural correlates of self-control, we recorded single-unit activity from the supplementary eye field (SEF) while the subjects performed the temptation task. We found that some SEF neurons were more active when the subjects succeeded in exerting self-control and stayed with the initial delayed large reward target (L-L stay) than when they failed in exerting self-control and switched to the immediate small reward target (L-S switch). Next, we inactivated SEF by cooling it. This caused a significant shift in the choice curve so that the subjects chose S more often at the initial choice and also switched from L to S at a shorter L delay.

Conclusions: Our behavioral results show that self-control is required to delay gratification. This internal behavioral control signal can vary in strength. Our electrophysiological recording and inactivation results suggest that neural activity in SEF is part of the network underlying this behavioral capacity. SEF activity has a causal role in exerting self-control and its function is likely related to the control of action to select and maintain actions that will lead to behavioral outcomes that are optimal in the long-term.

Acknowledgements: This study was funded by the NIH, grant #2R01NS086104

Disrupted Cortical Regulation of Striatal Value Signals Drives Self-Control Deficits in Incarcerated Criminal Psychopaths

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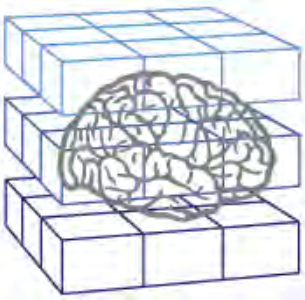
Objective: Psychopathy is a personality disorder with strong links to criminal behavior and substance abuse. While research on the disorder has primarily focused on emotional arousal and threat detection, some have suggested that aberrant value-based decision-making comprises an important route to antisocial behavior (Buckholtz et. al. 2010, Buckholtz 2015). Yet, little is known about circuit-level reward system dynamics in criminal offenders.

Methods: Here we used a mobile 1.5T MRI scanner to examine the relationship between value-based decision-making, brain activation and connectivity, and psychopathy in a sample of adult male incarcerated criminal offenders. Participants were scanned while performing an incentive-compatible intertemporal choice paradigm. We estimated individual discounting rates by fitting subjects' choices to a hyperbolic model of temporal discounting. We used each subject's discount rate to estimate the subjective value (SV) of each of the two choice options presented on every trial. Subjective value-related activity was assessed by using a parametric modulator reflecting the sum of the SV's of both options. In addition, we obtained resting-state functional connectivity scans and a clinical assessment of psychopathy (the Psychopathy Checklist-Revised; PCL-R).

Results: Higher levels of psychopathy were associated with heightened SV-related activity within the nucleus accumbens (NAcc) during intertemporal choice. In addition, both psychopathy scores and subjects' total number of convicted crimes were negatively correlated with the magnitude of functional connectivity between NAcc and ventromedial prefrontal cortex (VMPFC). In turn, NAcc-VMPFC functional connectivity strength negatively predicted the magnitude of NAcc SV-related activation during choice behavior, suggesting cortical regulation of striatal SV signals. Finally, we observed that psychopathy moderated the relationship between NAcc-VMPFC connectivity and NAcc activation. While a negative relationship between corticostriatal connectivity and striatal activity was evident in subjects with low PCL-R scores, this relationship was progressively abolished with increasing levels of psychopathy.

Conclusions: These findings indicate that prefrontal regulation of striatal SV signaling during intertemporal choice is perturbed in psychopathy. The degree of this dysregulation appears to track criminal convictions, suggesting that aberrant prefrontal modulation of subcortical SV signals may contribute to persistent self-control deficits and antisocial behavior in the disorder.

Acknowledgements:
This study was funded by the Brain and Behavior Research Foundation and the Alfred P. Sloan Foundation.



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Poster Session II
By Poster Number

Hunger Games: Does Hunger Affect Time Preferences?

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Objective: Classic economic theory focuses on static preferences and relies on the Homo Economicus assumption. However, there is growing evidence that cognitive, emotional and visceral states can mediate behavioral biases and shape preferences. For example, as Homo Sapiens, we know that we tend to make many important economic decisions, with potential long term consequences, when we are hungry and/or cognitively fatigued. This study draws parallel evidence from psychology, economics and neuroscience to test whether hunger and/or cognitive fatigue affect time preferences.

Methods: I conducted a controlled laboratory experiment with a 2x2-factorial design where I manipulated both the state of hunger (fasting) and/or the state of cognitive fatigue (arithmetical task) of participants making monetary intertemporal choices. Participants where required to fast for at least 3 hours before the experiment. The experimental design was implemented by varying the order of 4 experimental tasks: a) a decision task, used to elicit time preferences; b) an arithmetical task, used to induce cognitive fatigue; c) a blind tasting activity and filler tasks, used to satiate appetite; and d) a demographic questionnaire and auxiliary survey, used to collect additional information on individual characteristics and dietary practices. A total of 160 subjects participated in the experiment.

Results: I find that both hunger and cognitive fatigue increase monetary impatience, but only hunger affects time preferences. Hunger activates present bias by disproportionately increasing monetary impatience when choices involve immediately available monetary rewards. In contrast, cognitive fatigue increases the number of all-earlier allocations. I argue that the later may reflect a decrease in attention and an increase in heuristic-based choices. However, further works is needed to test this hypothesis. Interestingly, the interaction of both treatments also activates present bias but it also increases monetary patience. Also, consistent with previous findings individuals under the control condition (not hungry nor cognitively fatigued) display reasonable levels of discounting, present bias, and intertemporal elasticity of substitution.

Conclusions: Together these findings demonstrate that hunger activates present bias. Moreover, we know that the poor, who are more susceptible to food insecurity and as a result more likely to frequently experience hunger, tend to make more shortsighted economic decisions. Therefore, this study suggests that hunger may play an important role in behavioral poverty-traps.

Acknowledgements:
This study was funded by the Russell Sage Foundation and the University of California, Berkeley's Experimental Social Science Laboratory.

Value-based decisions are influenced by memory retrieval

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Objective: Memory can help guide decisions, but the mechanisms by which memory guides choices are not well understood. We hypothesize that memory is particularly influential when decisions cannot be made based on value alone, such as when deciding between similarly valued options. In the latter, sampling from memory may resolve choice, explaining why such decisions take more time.

Methods: 107 healthy adult subjects (Ss) participated across 3 experiments. All Ss first took part in a BDM auction. The auction furnished values (V_i) for appetitive snack foods. V_i were later used to form choice pairs, with paired items varying on $\Delta V=V_i - V_j$. In Exp 1, we asked Ss to indicate their preference between 2 items in a choice-reaction time design, without manipulating or measuring memory. Choices were classified as correct if Ss chose the item with higher V_i. Exp 2 was identical except that during the choice phase Ss were instructed to retrieve memories of experiences with the options before choosing. Choice reaction time (RT) and accuracy were measured. Exp 3 consisted of 4 phases: (1) an auction as above; (2) an associative memory encoding phase in which Ss associated foods with a neutral face or scene; (3) a choice phase, in which Ss indicated their preference between 2 foods then judged the gender/location of a face/scene; (4) a memory test. RT and accuracy were measured for choice, judgment and memory in phases 3-4.

Results: In Exp 1, we replicate previous findings: as choice difficulty decreased (i.e. $|\Delta V|$ increased), RT decreased and accuracy increased. In Exp 2, when Ss were asked to retrieve episodic memories associated with the options before the choice, they were overall slower and less accurate than in Exp1. Moreover, RT did not decrease as $|\Delta V|$ increased when memories were retrieved and Ss made incorrect choices, suggesting that the memory intervention altered V_i. Finally, adding an associative memory demand to the choice task in Exp 3 also changed RT and accuracy, such that RT decreased less and accuracy increased less as $|\Delta V|$ increased, compared to Exp 1. Exp 3 further revealed that memory vividness was related to choice accuracy and inversely related to choice RT, indicating that associative memory strength influenced choices and RT.

Conclusions: Together, the findings demonstrate that retrieval of memories alters choice RT and accuracy in value-based decisions. Memory demands during value-based decision making alter the subjective value of choice options. Preliminary results suggest a partial contribution of memory retrieval to decision time.

Acknowledgements: This study was funded by NIH grant R01DA038891. The authors thank Lucy Owen, David Borowski and Sean Raymond for help with data collection.

The evolution of uncertainty during the encoding of value

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Objective: The field of neuroeconomics has produced a wealth of work on how a decision-maker's brain copes with choices that have uncertain outcomes (i.e., economic risk, Shannon entropy, volatility), but so far has largely neglected the role played by the uncertainty inherent in the encoding of value. Borrowing a paradigm from perceptual decision-making, recent work has shown that it is possible to use reported confidence to measure the level of uncertainty (σ) generated during value comparison (cf., De Martino et al, Nature Neuroscience, 2013). Here, using a novel learning task, we study how uncertainty in the encoding of value evolves over time and how the precision ($1/\sigma$) in the value estimates shapes confidence during choice.

Methods: We tested these questions using a probabilistic learning task. Our task comprised two conditions: On Observation Trials (75%), participants were presented with the two arms of a bandit in which a computer randomly chose one of them, revealing its outcome. Participants were required to judge the value (average outcome) and report their uncertainty regarding their value judgment. On Choice Trials (25%), participants were instructed to pick the arm of the bandit that they thought would yield a higher reward. Upon choosing the arm and before seeing the outcome, participants also rated their confidence in this choice.

Results: We found that, in the Observation Trials, participants can closely track (and report) the evolution of the uncertainty in the value of each bandit. Using this setup, we were able to show that participants' responses conformed to an optimal Bayesian updating process. Furthermore, we found that choice confidence was driven by the precision in the perceived value estimates of each arm (chosen and unchosen).

Conclusions: Our results provide a novel account of how uncertainty in value judgments is constructed over time, and how the precision in the value representation for the chosen and unchosen option feeds into choice confidence. We also suggest that our results carry implications for how people arbitrate between exploration and exploitation.

Conflict of Interest: The authors declare no conflict of interest.

Acknowledgements: This study was funded by a Sir Henry Dale Fellowship awarded to B. De Martino by the Wellcome Trust.

Neural Subjective Value Representations Depend on Decision Features: Time Delay, Physical Effort, and Probability Discounting

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Objective: In the present study we attempt to dissociate behavioral preferences for different decision features to examine the convergence and divergence of neural representations of subjective value. Across a broad age range of healthy adults we examine neural subjective value representations in tasks where monetary rewards must be integrated with three decision features: time delays, physical effort, and probability.

Methods: 55 healthy participants between the ages of 22 and 83 (half female) completed 3T fMRI studies at Vanderbilt University. Each subject made choices between a smaller magnitude reward with shorter time delay and a larger magnitude reward with a longer time delay, between a smaller magnitude reward with a lower level of physical effort required and a larger magnitude reward with a higher level of physical effort required, and between a smaller magnitude reward with a higher probability and a larger magnitude reward with a lower probability in the respective time, effort, and probability tasks. Subjective values were modeled based on individual subject discount rates using a hyperbolic discount function and softmax decision function. This combination of value and decision functions fit the data better than three alternative models and a random responder model.

Results: We found that discount rates – preferences for short time delays, lower physical effort, or high probability – were not correlated across tasks. In spite of the apparent behavioral dissociation between preferences, we found overlapping subjective value-related activity in the medial prefrontal cortex when decisions involved time delays or probability. Interestingly, activation in the medial prefrontal cortex was not correlated with subjective value when decisions involved physical effort. Our effort discounting task was different than previous tasks in that we attempted to remove time or probability components (which are commonly confounded with effort). In this isolated effort task, subjective value was represented in the left anterior insula. Finally, there was a small area of overlap in subjective value representation in parietal cortex for both effort and time.

Conclusions: These results suggest that the tolerance of these three decision features is behaviorally and neurally dissociable. Interestingly, the regions that are critical for computing and/or representing subjective value have a high density of dopamine receptors. All participants also completed a PET scan; in the future we will examine whether individual differences in subjective value representation are related to individual differences in dopamine receptor availability.

Acknowledgements:
This study was funded by National Institute on Aging grants R01AG044838 and R00AG042596.

Discriminating Honest and Dishonest Actions using Functional MRI

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Objective: It is part of the human nature that people want to be honest, but sometimes people might lie if the benefit is great enough. Previous studies have identified several brain regions that are critical to decisions involving honesty. However, researchers have not studied the trade-offs between preferences for self-interest and honesty in a realistic setting, and the predictive relationship between brain activities and honesty has not been established yet. Here we combine newly available machine learning techniques with functional neuroimaging data to test our ability of predicting whether a subject was being honest or dishonest based on their brain activities.

Methods: Twenty-six adult subjects participated in the fMRI study. Each subject made a series of choices of sending one of two messages to an anonymous signal recipient, on the basis of which the recipient chooses one of two monetary allocations associated with the messages. In one condition (INFO), the participant must choose between sending a truthful message that sacrifices economic self-interest in favor of honesty or a false message that satisfies self-interest at the expense of being honest. In the control condition (PREF) containing identical monetary consequences, the participant does not need to deceive the recipient to reach the self-interested outcome. To locate brain regions where the activity patterns contain information about honesty, we use a model-based searchlight decoding approach to determine the locations in the brain where there is a statistical dependency between subjects' decision (selfish or altruistic) and the regional spatiotemporal activity patterns.

Results: Using paired comparisons on decisions with identical monetary consequences, we found that inclusion of honesty concerns in the INFO condition substantially increased altruistic giving compared to the PREF condition. We further found a set of brain regions where we are able to use the activity patterns to predict the subject being selfish or altruistic. Comparing the accuracy maps in the INFO condition to the PREF condition, we find a number of regions that overlap in the set of regions predictive of deceptive and selfish actions. In addition, we also find regions that are predictive of deceptive but not selfish actions, consistent with the idea that the deception draws upon a shared set of cognitive processes with other goal-directed behavior, but also recruits additional processes unique to deception.

Conclusions: These results provide initial insight into methods that can decode honest and dishonest behavior from brain activity in decisions with real payoff consequences.

Acknowledgements:
This study was funded by National Institute of Mental Health grant MH-098023 (MH) and the Hellman Family Faculty Fund (MH).

Epiphany learning and pupil dilation in the 2-person beauty contest

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Objective: Models of reinforcement learning (RL) are prevalent in the decision-making literature, but not all behavior appears to conform to the gradual behavioral convergence that is a central feature of RL. In some cases learning appears to happen all at once, particularly in problem-solving tasks. However, prior research on these "epiphanies" only show evidence of sudden changes in decision behavior. It remains unclear how such epiphanies occur and whether they can be predicted from non-choice data since the choice data are, by themselves, uninformative. Here, we aimed to test an evidence-accumulation account of epiphany learning using behavioral and eye-tracking data. In particular, we hypothesized that pupil dilation might predict the occurrence of epiphanies.

Methods: The task was a 2-person variant of the well-known p-beauty contest. In this task, two subjects each pick an integer from 0 to 10. The average of the two chosen numbers is computed and multiplied by 0.9 to determine the target. The subject who chose the number closest to the target is the winner and receives a cash reward (ties are broken randomly). In this game the optimal/dominant strategy is to choose zero. Each subject played 30 rounds of this game (with feedback) against randomly drawn choices from a database of 28 additional non-eye-tracked participants. To behaviorally establish the epiphanies, we offered subjects a chance in each round to "commit" to their current choice for the rest of the experiment. This commitment entailed a small cash bonus in each subsequent round but also meant that subjects could not change their number.

Results: 80% of subjects committed to a number at some point. Among these subjects, 53% of them committed to zero. In addition, another 14% of subjects, although they never committed, had choice sequences that converged to zero in the end. For the subjects who committed to zero we found that their pupil-size data were significantly different when comparing rounds immediately prior to the commitment round to earlier rounds. Furthermore, we were able to fit most subjects' behavioral and pupil data better with the epiphany learning model than with the traditional reinforcement model.

Conclusions: Behaviorally we observed that many subjects exhibited behavior more consistent with epiphany learning than with traditional reinforcement learning. Using the eye-tracking data we found internally driven changes in pupil diameter that corresponded to the timing of epiphanies (commitment tozero). These results provide evidence that epiphany learning is an important aspect of human behavior and that there are physiological markers of such learning.

Task-set selection in probabilistic environments: a model of task-set inference

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Objective: In uncertain environments, it is often unclear which action policy (task-set) is most advantageous. Appropriate task-set selection is dependent on an inference over probabilistic evidence: this inference establishes the latent world state, which subsequently determines task-set utility. It is currently unclear how well people integrate multiple sources of evidence, particularly when action feedback is unavailable. In this work, we use a Bayesian inference model to investigate how people differentially rely on separate classes of contextual information in the service of task-set selection.

Methods: 26 adult subjects completed a probabilistic context task where correct responses were determined by two task-sets that stochastically switched from trial to trial. A probabilistic cue (stimulus position), as well as non-uniform task-set transition probabilities (task-sets were likely to repeat) allowed the subjects to infer the applicable task-set on each trial. Subjects were first trained in this environment with feedback, and then tested with the feedback removed, decoupling task-set inference from action evaluation. Using a Bayesian model, we estimated individual subject's tendency to overweight the probabilistic cue in task-set selection, and defined a trial-by-trial metric of choice confidence based on the distance between model posteriors and the choice boundary between task-sets.

Results: Model predictions fit individual subject performance well, correctly predicting the choices 90% of the time. Parameter estimates showed that while most subjects integrate the probabilistic cue and task-set transition probabilities, the degree to which their choices conformed to the probabilistic cue was highly variable. In general, people overweighted the probabilistic cue over the transition probabilities when selecting task-sets. We also found that model confidence was negatively associated with reaction times such that subjects were faster on trials where the model was more confident in its decision.

Conclusion: These results demonstrate that subjects generally overvalue current information when selecting task-sets. In addition, the relationship between reaction time and model confidence suggests that model posteriors capture a latent decision process underlying task-set selection. Future work will pursue the potential neural instantiation of this decision variable with fMRI.

The influence of nutrition labels on binary food choices: computational modeling approaches

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Introduction: Food decisions occur frequently and are often situations of self-conflict, in that taste and health attributes have to be both weighted in the decision-making process. Values are computed dynamically, and appropriate attention manipulation might improve decision-making in terms of food choice and inducing self-control. In a first fMRI study, we showed that salient labels increase the subjective valuation of healthier food products. Red traffic light (TL) signaling activated a region implicated in self-control in food choice. This region, in case of red signaling, and the posterior cingulate cortex, in case of green signaling, showed increased coupling to the valuation system in the ventromedial prefrontal cortex. Our results suggest that explicitly directing attention towards nutritional values using salient labels triggers neurobiological processes that resemble those utilized by successful dieters choosing healthier products. Drift Diffusion Models (DDMs) provide a mathematical framework to understand decisional processes by decomposing choice and reaction time data into internal processing components. DDMs yield empirically validated insights into potential sub-optimalities of individual decision-making.

Methods: 44 participants rated the taste of 100 food products. In a binary choice task, they chose 350 times between a healthy and an unhealthy product. In each trial, products were labeled either with a TL or a numeric label. The probability of healthy choice depending on the label was analyzed using a multilevel logistic regression analysis. In the DDM analyses, we separately let the drift rate estimate, starting point, boundary separation and non-decision time vary for the two labels and compared the estimates for the two labels using paired t-tests. Model fit was confirmed using Monte-Carlo simulations. To model rating-specific drift-rates for the two labels, we used a jackknifing procedure.

Results: Our results show that the probability of healthy choices increases when products are labeled with a TL label. This bias could be modeled with a DDM. Only drift rate estimates differed significantly between the two labels. The drift rate was increased in case of TL labels across ratings and highest when the unhealthy product was preferred.

Discussion: Differences in drift rate estimates suggest that nutrition information as well as taste preferences are integrated into a single source of evidence during the decision process. A higher drift rate suggests more efficient information processing or higher quality of the stimulus in case of a TL label. In ongoing work, we want to include eye-tracking for attentional DDMs to better understand these effects. These multi-modal investigations are important to better understand underlying cognitive processes, as well as improving public policy interventions.

Alternative Interpretation to Action-Value Neurons in the Striatum

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Objective: It is generally accepted that the firing rates of certain neurons in the striatum encode the value of action-specific rewards. This hypothesis is primarily based on electrophysiological recordings from single neurons in the striatum, while the animal learns to choose the more rewarding alternative in a repeated-choice task (Samejima 2005; Lau and Glimcher 2008; Ito and Doya 2015). Here we show that while the evidence for the involvement of neurons in the striatum in reward-related learning and decision-making is strong, the experimental results are consistent with other forms of operant learning and decision-making that do not involve a calculation and representation of "values".

Methods: To that goal, we study a network model, in which decisions between alternative actions are made through competition of populations of neurons, whose firing rate is learned using a covariance-based plasticity rule (Loewenstein and Seung, 2006). As a consequence of this learning rule, the model network learns to prefer the more rewarding alternative without any information in the network about the "values" of the different actions.

Results: We show that a large fraction of model neurons, up to 60% of network neurons, are endowed with the statistical properties that have previously been used to identify neurons as action-value neurons. Specifically, the firing rate of these neurons is significantly correlated with action-values calculated according to Q-learning models.

Discussion: We generalize the results and show that many network models yield activities that can be misinterpreted as representing action-values. In short, we show that the interpretation of neurons' activities as representing action-values can arise from a hidden assumption that changes in the firing rate of the neurons can only result from learning. If this assumption is violated then a large fraction of network neurons may be mislabeled as action-value neurons. This is particularly problematic in block-design experiments. We discuss alternative experimental designs for the identification of action-value neurons.

References

- Ito M, and Doya K (2015) Distinct Neural Representation in the Dorsolateral, Dorsomedial, and Ventral Parts of the Striatum during Fixed- and Free-Choice Tasks. *The Journal of Neuroscience* 35:3499–3514.
- Lau B, and Glimcher PW (2008) Value representations in the primate striatum during matching behavior. *Neuron* 58:451–463.
- Loewenstein, Y, and Seung SH (2006) Operant matching is a generic outcome of synaptic plasticity based on the covariance between reward and neural activity. *Proceedings of the National Academy of Sciences of the United States of America, Volume 103*, Number 41:15224–15229.
- Samejima K, Ueda Y, Doya K, and Kimura M (2005) Representation of action specific reward values in the striatum. *Science* 310:1337–1340.

Beyond Delay Discounting: Intertemporal Choice Between Non-Unitary Rewards

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Objective: Intertemporal decision-making is most commonly studied in choices between two singular outcomes available at discrete times in the future. However, even canonical intertemporal decisions, such as that between fruit salad and cake, involve conjunctions of outcomes: salad and better health versus cake and worse health. For decisions involving combinations of outcomes, the discounted utility (DU) framework asserts that the utility of combinations is equal to the sum of the utilities of the outcomes assessed individually (independence axiom). We tested this core assumption of the DU model and show that it is systematically violated for choices between pairs of monetary outcomes. We built a model incorporating evaluative properties in addition to delay discounting and tested whether it predicted behavior better than the DU framework.

Methods: 206 subjects completed the behavioral study with three phases. Subjects first completed a titration test that elicited indifference points for individual monetary rewards at different points in the future. Then, the individualized indifference points were combined to pairs of outcomes and we tested whether subjects remained indifferent in these combined choices. Lastly subjects were recalibrated to ensure that they were truly indifferent between the future outcomes identified initially.

We analyzed the behavioral data by comparing the DU model to a model that incorporates additional decision strategies including (1) preference for improvement, and (2) preference for larger total reward. We fit both models to behavioral data and tested whether the additional evaluative properties significantly improved model fits.

Results: Discounting behavior in our titration procedure reflected stylized effects of delay discounting (magnitude, sign, and delay effects) and had high test-retest correlation ($r = 0.7$, $p < 0.001$). Thus, our calibration procedure elicited true indifference points. χ^2 tests indicated that preferences deviated significantly from indifference for 89% of the choices involving combinations of rewards, thus systematically violating the DU model. Our discount function consistently accounted for these violations of indifference.

Conclusions: These results suggest that hyperbolic discounting systematically fails when extended to more complicated decisions but behavior can be accounted for well by incorporating viable decision strategies in quantitative models.

The hysteresis of time-value curvature caused by directional gain/loss delay variation

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Objective: Although it is known how delay affects the utility of a prospect, there has been little discussion about the way by which delay cause changing mind about different options. In this study our hypothesis is as follows: in a set of time-discounting questionnaire, the direction of changing delay has effect on decisions. It means that in ascending/descending delay, the participant valuate options differently. This phenomenon causes a hysteresis effect in time-value curve. To have an overview on the slopes of time-value curvature, unlike most studies in this field, a slider is used to show the confidence of the participant for choosing an option. This kind of questionnaire gives us the opportunity to study the hysteresis region accurately.

Method: 60 adult subjects (30 female) participated in this study. To have a proper sample of the society, these participants are selected from three different groups; students, private and government employees. The questionnaire was prepared online and the choices had to be made between a probable immediate gain/loss, and the same certain gain/loss with delay. These delays were applied to the options in two ways; an ascending delay range from two hours to two years, and a decreasing delay with the same domain. The choice between two options can be done with five levels of confidence.

Results: In accordance with our hypothesis, we found the hysteresis in the time-value curve. In addition these results illustrate that any changes in the probability causes a drift in the time-value curvature and affects the width of the hysteresis part of the curve. Moreover, results indicate that transition from one option to the other one is not a rapid change and occurs smoothly (based on the changes in confidence value).

Conclusion: The hysteresis of time-value curvature confirms that the starting point and the direction of changing the value of delay have effect on decisions. Additionally, type of the hysteresis shows that people stay consistent with their first selection, and based on the level of confidence in obtained results, changing mind from one option to the other one accomplishes with a smooth slope. This study proposes a new model for updating prospect theory by considering previous selections in valuation of a new given problem.

Ego Depletion and Risk Attitudes: Is There a Causal Effect?

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Objective: We study the effect of willpower depletion on risk attitudes. Risk preferences are an integral part of economic theories of decision making. Incorporating findings from psychology, the dual-self model by Fudenberg & Levine (*AER* 2006, *AEJ: Micro* 2011) posits that a central determinant of risk attitudes is the ability to exert self-control. More specifically, the model predicts that lower levels of self-control induce stronger risk aversion for stakes within a particular range. While some empirical evidence on the relation between self-control and risk attitudes exists, it is both lacking and inconclusive. Our objective is, therefore, to inform economic theory by testing a core prediction of the Fudenberg–Levine model and to provide sound empirical evidence on the effect of willpower depletion ("ego depletion") on risk attitudes.

Methods: Using the "approximate dual-self model" by Fudenberg et al. (*J. Econ. Psych.* 2014), we derive hypotheses for choice between risky monetary payoffs in a state of low self-control, compared to a state of regular self-control. We test these hypotheses in a lab experiment. The treatment group ($N = 152$) performed an ego depletion task that is well-established in the literature (crossing out letters; see the meta-analysis by Hagger et al., *Psych. Bull.* 2010). The control group ($N = 156$) performed a similar but non-depleting task. Immediately after the respective task, we obtained precise measures of subjects' risk attitudes by presenting each subject with four fine-grained choice lists in which each row consisted of a binary lottery choice.

Results: Contrary to the theoretical predictions, we do not find any evidence for increased risk aversion after ego depletion. A power analysis reveals that each of our choice lists has a power of over 99.9% for detecting an effect size of $d = 0.62$—the average effect size measured by Hagger et al. for the depletion task that we use—at significance level $\alpha = 0.05$.

Conclusion: We find no support for the link between self-control and risk attitudes that is proposed in the Fudenberg–Levine model and that has also been suggested in the psychology literature. It is possible that the ego depletion task failed to reduce self-control in our subjects, despite being well-established. This would be in line with Xu et al. (*PLoS ONE* 2014) who failed to replicate previously reported effects of ego depletion. Moreover, Carter & McCollough (*Front. Psych.* 2014) find evidence for small-study effects and publication bias. Correcting for these, they find that average depletion effects are indistinguishable from zero. Either way, the alleged role of self-control in shaping risk attitudes may have to be reconsidered.

Why are decisions "noisy"? Evidence for stochastic discount rates in intertemporal choice.

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Objective: One of the principal goals of neuroeconomics is to explain the stochastic component of choice behavior. Traditionally, random utility models and their neural variants have assumed that choice variability comes from random perturbations of either subjective value (SV) or downstream representations independent of the valuation process. For delay-discounting models this has meant a discount rate that is fixed for each individual and trial-to-trial variability that is Gaussian or logistic and centered around the expected SV for each trial. We mined delay-discounting data from over 600 human subjects and 8 experiments to probe the structure of choice variability and test whether it is consistent with the standard models.

Methods: We analyzed 7 binary choice experiments and an additional experiment in which subjects bid on a single monetary reward of varying delays. We fit data to several different models of delay discounting and analyzed the resulting parameter space and model residuals.

Results: Surprisingly, we found a significant correlation between discount rate and the magnitude of choice variability, with steeper discounters showing greater trial-to-trial deviations from model predictions. This relationship held regardless of the model of the discount function used, including a non-parametric form that only required SV to decrease as a function of delay. A direct mechanistic link between discount rate and variability was corroborated by one study involving patients with damage to ventromedial prefrontal cortex, who showed both increased discount rates and a proportional increase in choice noise that was predicted by the normal population statistics. We also found a significant autocorrelation among trial-to-trial deviations, with unexpectedly patient choices predicting the same deviation over the next ~10 trials, and similarly for unexpectedly impatient choices. Both analytical results and simulations demonstrate that the link between discount rate and choice variability can be parsimoniously explained by a class of models with moment-to-moment variability in discount rate itself rather than SV.

Conclusions: The data and modeling suggest that each individual implements a stochastic discounting policy, with moment-to-moment variability in discount rate that spans multiple experimental trials. This theory is in line with recent studies in economics on the stochastic transitivity of subjective preferences. On a neural level, the model suggests that variability in intertemporal choice may stem from global fluctuations in the parameters computing subjective value, rather than purely random neural noise per se.

Acknowledgements: This study was funded by the NIH, grants R01 MH098899 and R01 DA029149.

The effects of reciprocity on cooperative decision in gain and loss context and its relevant neural mechanisms

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Objective:
Reciprocity is one of the most important factors for the establishment and maintenance of relationships between individuals. Receiving favor from others but not reciprocating will prevent setting up of stable and long-term cooperative partnerships with others. Previous research found that individuals are conditional cooperators, indicated that most people cooperate if others also cooperate. However, these results are based on the sharing gain context, few studies have ever been engaged in the cooperative decision in sharing loss context. The present study aimed to test the hypothesis that partners' prior reciprocity will affect cooperative decision differently in gain and loss context, and identify the neural mechanisms by which reciprocity on cooperative decisions.

Methods:
Thirty-nine Chinese adult subjects participated in the study (19 female, mean age = 21.92 ± 2.45). Subjects as trustee first played 30 rounds of trust game with different investors. Following this behavioral testing session, subjects were scanned using 3T fMRI while they played a modified public goods game (PGG), a standard experimental measure of cooperation, in gain and loss context with a varying level of reciprocity individuals. We analyzed our neuroimaging data using the general linear model; for each trial, we use participants' choice in PGG as a parametric modulation to create a statistical contrast between the contribution in sharing gain and sharing loss context.

Results:
Behaviorally, we found that individuals contributed most in sharing gain context but least in sharing loss context when they were playing with high reciprocity individuals compared with people from other level of reciprocity individuals. Interestingly, this effect was much more significant in gain than loss context. In terms of neural activation, cooperative decision in gain context versus non-cooperative decision in loss context was positive correlated with the activation in the brain area of bilateral ventral striatum (VS), anterior cingulate cortex (ACC), ventral medial prefrontal cortex (vmPFC) and posterior cingulate cortex (PCC). Secondly, comparing viewing high-reciprocity versus low-reciprocity led to increase activity in the bilateral insula, ACC and vmPFC.

Conclusions:
In summary, the present research shows that partners' prior reciprocity has a demonstrable but different effect on cooperative behavior in gain and loss context, and that the motivation to cooperate may be associated with both reward processing (the so called 'warm glow' effect of altruism) as well as with theory of mind mechanisms.

Acknowledgements:
This study was funded by 973 Program (2014CB744600); NSF China (81471376); the foundation of the National Key laboratory of Human Factors Engineering (HF2012- K-03); the Fundamental Research Funds for the Central Universities (2012CXQT01) and Chinese Scholarship Council.

Dynamic pupil dilations predict the precision of both perceptual and value-based choices

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Objective:
Previous work has shown that pupil size increases during demanding decisions. These decision-related changes in pupil dilation are proposed to reflect activity in central neuromodulatory arousal systems (1, 2) that are thought to phasically boost neural gain mechanisms (2, 3). Here we test whether such pupil-indexed neural gain changes can predict the precision of both perceptual (accuracy) or value-based (preference consistency) choices.

Methods: During fMRI, we measured pupil size while thirty-five healthy participants alternated between blocks of value-based and perceptual decisions that were matched for visual stimulation, task requirements, and motor output. We regress the trial-by-trial precision of both choice types on phasic pupil changes during the decision-phase, while controlling for the perceptual and value-based evidence (difference value, DV) and overall magnitude (summed value, OV) driving both choices. The imaging data were analyzed with the identical regression.

Results: We find a large negative effect of decision-related pupil dilation on reaction times (both tasks $p < 0.001$), despite controlling for DV and OV, indicating that trial-by-trial neural gain changes can significantly impact on the speed of the choice process. More strikingly, decision-related pupil dilation was also strongly predictive of accuracy and preference consistency in perceptual and value-based choices respectively (both $p < 0.001$), on top of any effects predicted by OV and DV. Thus, phasic neural gain changes during decision formation also predict choice precision. The corresponding neural data show that pupil dilation during both tasks correlated with increased activity in IPS, dACC, dlPFC and fusiform gyrus (all cluster-corrected $p < 0.05$), suggesting that increased neural gain in these areas mediates the enhancements of choice precision and speed.

Conclusions: Our results indicate that phasic enhancements of neural gain can be detected in pupil dilation and predict the precision and speed of both perceptual and value-based choices. Decision-related pupil dilation may therefore provide an easily accessible measure for future research on healthy and maladaptive choice behavior.

1. Yu AJ (2012) Change is in the eye of the beholder. *Nat Neurosci* 15(7):933-935.
2. Aston-Jones G & Cohen JD (2005) An integrative theory of locus coeruleus-norepinephrine function: Adaptive gain and optimal performance. *Annu Rev Neurosci* 28:403-450.
3. Parikh V, Kozak R, Martinez V, & Sarter M (2007) Prefrontal acetylcholine release controls cue detection on multiple timescales. *Neuron* 56(1):141-154.

Acknowledgements:
This work was supported by grants of the SNSF (105314_152891, CRSII3_141965 and 51NF40_144609) and the SNSF NCCR Affective Sciences to C.C.R.

The spillover effects of attentional learning on value-based choice

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Objective: Several studies have shown that gaze duration and object salience can influence decisions but these studies are either correlational or directly interfere with the stimuli or choice process, leaving them open to alternative interpretations. Here we aimed to provide definitive evidence that manipulating attention itself biases choice.

Methods: A total of 90 undergraduate Ohio State University (OSU) students participated in two studies (48 in Experiment 1, 41 in Experiment 2). Each study consisted of three stages. First, subjects rated 91 food items from -10 to +10 based on how much they would like to eat each item. In the second stage, subjects completed 200 trials of a visual search task to find a rotated T amongst many rotated L's and to indicate whether the T was oriented to the left or to the right. In the first experiment, participants were more likely to receive a high reward if the search target was on one side of the display than the other (reward cueing). In the second experiment, participants were rewarded equally for correct answers on either side of the display, but targets were more likely to appear on one side than the other (probability cueing). Subjects earned cash for each correct response. In the final stage, subjects completed 130 trials of a choice task where they chose between two food items, one presented on the left and one on the right side of the screen. One of these choice trials was chosen at random at the end of the study, and subjects received whichever item they had chosen on that trial.

Results: Subjects in both experiments were more likely to choose food items appearing on the side of the display that was previously more rewarded or more likely to contain the search target. Furthermore, in the second experiment, subjects were significantly faster at finding the search target when it occurred on the more likely side, and the size of this reaction-time difference predicted a subject's choice bias during the later food-choice task.

Conclusions: In two separate experiments we used different attentional learning techniques to train subjects that one side of the screen was either more likely to yield a high reward (Experiment 1) or more likely to contain the search target (Experiment 2). Both manipulations caused subjects to become spatially biased in a subsequent food-choice task. These results provide direct evidence that the deployment of attention influences value-based choice.

Uncertainty, ambiguity and entrepreneurship

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Objective: Entrepreneurs are known to show a higher tolerance of uncertainty than other people (e.g., Sexton and Bowman, 1986; Begley & Boyd, 1987, Knight, 1921) and their ability to tolerate uncertainty may partly explain why some people become entrepreneurs. To test the hypothesis that entrepreneurs do not react as emotionally to increasing ambiguity as other people we compare the behavior and brain activation of entrepreneurs and workers who have managerial responsibilities.

Methods: Altogether 43 healthy male subjects participated in the fMRI study (20 entrepreneurs and 20 workers, three participants were excluded because they misunderstood the task). The experiment consisted of two separate sessions. In the first session, subjects filled out questionnaires on their risk preferences, confidence, optimism and socioeconomic and entrepreneurship / work background. In the fMRI session, subjects were presented a variety of "lottery tickets". The task of the subjects was to state minimal prices at which they were willing to sell (WTS) each one of the lottery tickets (the Becker-DeGroot-Marschak -mechanism). There were 98 trials, half of them risky and half ambiguous. Subjects stated a minimum selling price for the lotteries by moving a cursor on the computer screen. Subjects were also told that at the end of the experiment two lotteries would be randomly selected and played for real money. We analyzed the fMRI data using the general linear model.

Results: On average, entrepreneurs priced the lotteries, risky and ambiguous, 13.7% above their expected value whereas managers' average WTS fell below the expected value by 3.5 per cent. OLS panel regressions explaining the relative WTS by the entrepreneurial background and the lottery ambiguity level confirm that ambiguity significantly decreases relative WTS, low ambiguity 4.7 percent and high ambiguity 20.5 percent of the expected value. Ambiguity affects the pricing decisions of the entrepreneurs significantly less than the pricing decisions of the managers even after controlling for individual differences in the risk attitude. In the preliminary fMRI data analysis, we found that risky and slightly ambiguous lotteries are associated with insula and medial prefrontal cortex activities when compared with highly ambiguous lotteries. These brain areas have previously been related to emotional arousal and valuation, respectively.

Conclusions: Our data suggests that increasing ambiguity does not increase affective processing in entrepreneurs but in contrast may decrease it. We speculate that this may relate to higher ambiguity tolerance among entrepreneurs than other people.

Acknowledgements: This study was funded by the research project aivoAALTO (Aalto University), the Yrjö Jahnsson Foundation, and the Research Foundation of Cooperative Banks, Finland.

Neural Networks Potentially Underlying Asset Trading: A Combined Herding/Rationality Choice Paradigm for Neuroimaging

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Objective: Asset-price bubbles, which represent a longstanding anomaly in economics, have recently attracted the attention of neuroeconomists. For example, a functional magnetic resonance imaging (fMRI) study of lab asset-trading markets with price bubbles (Smith et al., 2014) found that activity in nucleus accumbens (NA) and anterior insula (AI), respectively, was associated with bubble-building asset buying and bubble-bursting asset selling. We conducted a systematic literature review to develop a hypothesis about the role of NA- and AI-related neural networks in asset trading, including that underlying price bubbles and crashes. To test this hypothesis, we also developed a novel psychometric and neuroimaging choice paradigm.

Methods: Neuroimaging studies were reviewed to seek NA- and AI-related neural networks and behavioral processes potentially involved in asset trading underlying financial-market price bubbles and crashes. We also reviewed experimental choice paradigms that involve behavioral processes implicated by the reviewed neuroimaging studies.

Results: Many fMRI studies found AI activations associated with deliberation, which depends on activity in the frontoparietal network, whereas NA was activated during herding (i.e., following others' decisions). Therefore, we hypothesize that NA-related herding may drive bubble-building asset buying. AI activation may represent a warning signal (Smith et al., 2014) that triggers deliberation-based asset selling and price crashes. Frontoparietal network-based deliberation may predominate during non-bubble periods of financial-market activity. In summary, we hypothesize a balance between NA-related herding neurocircuitry and the deliberative frontoparietal network, with the balance tipping toward herding during asset-price bubbles. To test for this balance between neural networks, we used the choice-experiment literature as a guide for designing an event-related herding/rationality choice paradigm that is useful in neuroimaging studies. Our design enables psychometric tests of herding and rationality by adapting the budget-allocation task of Choi et al. (2014). The deliberation-inducing trials of Choi et al. (2014), which enable a test for rationality with the Critical Cost Efficiency Index, are interspersed with trials that allow herding when subjects may align their decisions with those of a reference group, thereby enabling the calculation of a Herding Index.

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Conclusion: Herding- and deliberation-related neurocircuitry, potentially involved in different business-cycle phases, may be elucidated with our herding/rationality neuroimaging paradigm.

Acknowledgements:
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Might the brain disregard social cognition information in economic contexts?

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Objective. Social decision-making tasks often recruit social cognition brain regions (including MPFC, STS, TPJ, precuneus[1-4]) in addition to regions supporting economic decision-making (including striatum, amygdala, MOFC)[5]. This spontaneous recruitment interrupts social learning in uncertain economic contexts[6], but can be regulated during economic tasks to guide valuation processes[7]. Such neuroeconomic results suggest that the brain may disregard social cognition information when making decisions about people in economic contexts. We test this hypothesis in a labor context with online and consequential data.

Method. Four hundred online participants were put in a position to possibly hire "employees" to perform two tasks. They first observed employees' high or low donations and time estimation game performance, relative to a population mean. They then generated social cognition information by completing a series of tasks. Next, they completed a memory test about employees' behavior, before deciding whether to invest with employees in either a trust game or rock estimation game, and reported their confidence in their decisions. We measure the extent to which participants use social cognition information to guide investment decisions. Additionally, we use effect sizes in brain data[5] as coefficients in a model to predict social investment decisions. We then test axioms to compare patterns in the general linear model of the online and model-generated data to existing consequential data[8].

Results. We find that online participants replicate the pattern of consequential investment behavior for employees depicted as high performers. Participants continue to dissociate moral/sociable and ability domains of social cognition information for each game, and use moral/sociable information more extensively than ability information. However, for employees perceived as low performers, participants utilize the social cognition information less, relying more on normative estimates of performance. Finally, model-generated data based on online participants better fits responses towards low than high performing employees.

Conclusion. These data are consistent with claims dissociating economic contexts from social contexts[9-10], and suggest that the brain may disregard social cognition information in economic contexts to improve outcomes. Specifically, social cognition information seems less relevant when making decisions about people that are low performers.

References.

[1]Amodio & Frith, 2006
[2]van Overwalle, 2009
[3]Harris, McClure, van den Bos, Cohen, & Fiske, 2007
[4]van den Bos, McClure, Harris, Fiske, & Cohen, 2007
[5]Lee & Harris, 2013
[6]Lee & Harris, 2014
[7]Harris, Lee, Capestany, & Cohen, 2014
[8]Harris, Lee, Thompson, & Kranton, 2015
[9]Fiske, 1992;
[10]Shampanier, Mazar, & Ariely, 2007

Frontoparietal Activity During the Intertrial Interval Predicts Switching in Intertemporal Choice

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Much prior work in intertemporal choice (ITC) models series of binary choices as *independent* decisions. However, we have previously demonstrated that across consecutive trials, 1) participants switch (between sooner-smaller and larger-later options) less often than would be predicted by the assumption of trial independence, and 2) switching is predicted by longer reaction time during the previous trial. We sought to replicate these behavioral findings regarding behavior in consecutive ITC trials, and to relate these switching-related findings to neural activity as measured by fMRI.

First, in three separate intertemporal choice datasets (one of which has been previously published), we replicated previously reported behavioral findings ("streakiness" in choice across consecutive preference-matched trials, and an increase in switching immediately following long RT trials). Second, we reanalyzed fMRI data for N=48 and N=45 participants acquired during 2 studies where these behavioral findings were observed (Luo et al 2012, and Clewett et al 2014, respectively). Analysis focused on the left- and right- Frontoparietal networks, which have previously been implicated in intertemporal decision-making (e.g., McClure et al 2004; Clewett et al 2014). No consistent pattern was observed for the FPN activity during the decision-making period for switch vs. non-switch trials. However, in both datasets, lesser deactivation of the FPN networks during the intertrial interval predicted greater likelihood that the participant would switch on the subsequent trial. This was significant for the right FPN in both data sets and significant for the left FPN in one and marginally significant for the second.

Based on these findings, we suggest that activity during the intertrial interval may be a mediator of the robust effects observed for switching behavior across consecutive trials.

Acknowledgements:
This study was funded by the National Institutes of Health, R01DA023176

Haptic and Visual Descriptive Elements in Preference Formation

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Objective: A relevant question in real-estate marketing is to decide how to present the floorplans to the customers: with or without descriptive elements, such as furniture, or with interactively appearing elements. We tested the hypothesis that the presentation style influences preference formation for traditional and modern types of apartments. We used three presentation styles (floorplans with and without furniture, and floorplans where furniture emerged with haptic manipulation), and tested whether presentation style influences preference ratings and evoked brain activations.

Methods: Thirty adult subjects participated in the study. Subjects were familiarized with 18 printed floorplans prior to the fMRI scanning, each floorplan for 30 s. Half of the floorplans depicted traditional square-edged apartments and half round-edged apartments that are locally perceived as modern. Six (3 round-edged) floorplans were presented without furniture, six with furniture, and six on a special paper where the furniture appeared as the subject moistened the floorplan with a wetted finger. Each floorplan was presented to the subjects in the fMRI scanner four times without furniture. The subjects were occasionally prompted with a question asking for their preference rating. This question was asked once for each floorplan. We analyzed the fMRI data using the general linear model, and run repeated measures analysis of variance.

Results: Presentation style influenced preference ratings differentially for the two types of apartments (significant interaction, $p<.05$). The square-edged apartments were found significantly more preferred when they had been presented without furniture ($p<.05$) whereas round-edged apartments received higher preference ratings when they had been presented with furniture. When the subjects viewed the floorplans that they had experienced on the special paper vs. the floorplans with furniture, fMRI data revealed increased brain activation in the rostral cingulate zone that has previously been associated with internally selected actions. The round-edged apartments were associated with activation in the vicinity of parahippocampal place area when compared with square-edged ones, which may reflect a higher need for spatial perception.

Conclusions: The results suggest that the presentation style influences the preference for floorplans. It seems that the traditional square-edged apartments are better to be presented without descriptive elements, and the more modern round-edged apartments with them. We speculate that experience with haptic descriptive elements may strengthen the internal representation of the floorplans.

Acknowledgements:
This study was funded by Tekes (NeuroService-project). We thank Leeni Minkkinen for excellent research assistance.

Neuroanatomical markers of individual differences in delay discounting: a voxel-based morphometry study

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Objective: People have a tendency to devalue future rewards relative to immediate ones, a phenomenon called delay discounting. Discount rates vary dramatically across individuals, and are associated with a variety of personal and environmental factors, including substance abuse history, school performance, and financial stability. Over the last decade much has been learned about neural activity underlying the delay discounting (e.g., activation in the medial prefrontal cortex (MPFC), ventral striatum, and posterior cingulate cortex associated with subjective value of delayed rewards; Kable and Glimcher, 2007; Peters and Büchel, 2011), yet relatively little is known about the relationship between anatomical structure and delay discounting.

Methods: A total of 267 individuals from two data sources (n's equal to 136 and 131 respectively) were included in this study. All participants completed an incentive compatible delay discounting task and were scanned with the same MRI scanner. Voxel-based morphometry analysis was used to determine neuroanatomical correlates associated with delay discounting. Statistical analyses were performed in a merged data set to increase statistical power, and in each data set individually to confirm the robustness of conclusions.

Results: Our whole-brain analysis with the merged data set revealed that discounting rates were positively correlated with both gray matter volume (GMV) and white matter volume (WMV) in the MPFC and negatively correlated with GMV in the temporal pole and WMV in a region adjacent to the hippocampus and caudal part of the striatum. The negative correlation between GMV in temporal pole and delay discounting was particularly robust, as overlapping significant regions were found in both datasets individually.

Conclusions: Our findings reveal a stable neuroanatomical marker for delay discounting, particularly the temporal pole. Given that this region shows pronounced susceptibility artifacts, its functional role in discounting may have been missed in previous fMRI studies. We speculate that anatomical structure in this region may correlate with individual differences in episodic future thinking, as the temporal pole is part of the default mode network implicated in episodic future thinking (Buckner and Carroll, 2007; Schacter et al., 2007), atrophy in these regions is accompanied by deficits in episodic future thinking (Irish et al. 2012), and manipulations that encourage episodic future thinking reduce delay discounting (Peters and Büchel, 2011).

Acknowledgements: This study was funded by NIH grants # R01CA170297 and # R01DA029149.

References:

Buckner RL, Carroll DC. Self-projection and the brain. Trends Cogn Sci. 2007;11:49-57.

Irish M, Addis DR, Hodges JR, Piguet O. Considering the role of semantic memory in episodic future thinking: evidence from semantic dementia. Brain. 2012;135(Pt 7):2178-91.

Kable JW, Glimcher PW. The neural correlates of subjective value during intertemporal choice. Nat Neurosci. 2007;10(12):1625-33.

Peters J, Büchel C. The neural mechanisms of inter-temporal decision-making: understanding variability. Trends Cogn Sci. 2011;15(5):227-39.

Schacter DL, Addis DR, Buckner RL. The prospective brain: Remembering the past to imagine the future. Nat Rev Neurosci. 2007;8:657-61.

Corticostriatal representation of information value during ambiguous decision-making

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Objective:

Under conditions of ambiguity, people are required to make decisions based on incomplete knowledge. Previous research has found that this ignorance-based uncertainty has negative effects on how people assign value to ambiguous gambles. In this work, we turn our attention towards the neural and behavioral impact of (ambiguity-reducing) information. In particular, we examine how incremental information that is favorable or unfavorable to a desired outcome influences valuation of an ambiguous financial prospect and how this information is represented in the brain.

Methods and Results:

We collected behavioral and fMRI data from 34 participants who received varying levels of information about financial gambles. In this "Pro/Con" task, participants indicated their willingness to purchase fixed-price tickets for several independent gambles, each representing a poker chip being randomly drawn from a bag of exactly 100 red and blue chips. The underlying composition of the bag differed on each trial, and participants were given partial information about the amount of red chips and blue chips it contained. (The number of chips remaining unidentified was also indicated.) A red chip draw resulted in a monetary payout; a blue chip resulted in no payout. Thus the number of red chips revealed represented the amount of favorable information while the number of blue chips revealed represented the amount of unfavorable information. Both types of information were parametrically varied between 0 and 50.

Behaviorally, increasing the amount of information revealed (e.g. the number of identified chips) increases participants' willingness to purchase. In addition, we find an asymmetric influence of favorable over unfavorable information on willingness to purchase, replicating our previous behavioral research. Whole brain analyses reveal that activity in dlPFC, striatum, and areas in OFC (e.g. gyrus rectus) significantly correlate with the amount of information (favorable+unfavorable) revealed. Strikingly, NAcc appeared to track increasing amounts of information, even when this information was unfavorable. By contrast, OFC and dlPFC activity varied specifically according to the degree of favorable information.

Conclusions:

We show that under ambiguity, the amount of information that is available is tracked by reward-related circuitry, and there are differences in this representation for favorable and unfavorable information. Further, these data suggest that NAcc represents the value of information in a valence-independent fashion.

Attention and choice across domains

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Objective: People tend to choose items that draw their attention. Previous research has demonstrated significant relationships between attention and choice in a variety of different value-based settings. However, as is the case in most decision research, these relationships have been studied and modeled separately in each setting. Here we aimed to bridge these gaps by studying the consistency of the decision-making process across several decision-making tasks (food, risk, and social choice). We investigated both how the link between attention and choice varies within an individual across tasks and whether the strength of that link correlates with other measures of attention.

Methods: Each subject first rated the appeal of 147 food items on a scale of -10 to +10. Following the rating task, subjects made a series of incentivized choices in a variety of domains (food, risk, and social) while we tracked their eye movements. There were four distinct choice tasks, each with 200 binary choice trials. In the two-food task, subjects indicated their preference between two food items. Similarly, in the four-food task, subjects chose between two pairs of food items, where each pair indicated a 50-50 gamble between the two foods. In the risk task, subjects chose between two 50-50 monetary gambles. Finally, in the social task, subjects chose between two monetary allocations between themselves and another subject. After finishing these four choice tasks, subjects completed a final non-choice task to measure their attentional gradient. At the end of the study, one trial from each task was selected and played out.

Results: As in previous work, we found that while looking time generally does not correlate with value, it does predict choices. Across tasks we found a remarkably consistent pattern of results where a 0.5s looking-time advantage for one side translates to an increase in choice probability of ~25%, and at indifference the probability that the last fixation is to the chosen item is ~70%. We also observe that subjects with strong attentional influences in one task are likely to have strong attentional influences in the other tasks. Finally, we see a significant correlation between a subject's average attentional influence (across tasks) and their attentional gradient.

Conclusions: As anticipated, we found correlations within subjects and across tasks in terms of how attention influences their choices. Across subjects, we find relationships between the sharpness of spatial gradient, attentional weighting, and subsequent choice. Together, these connections provide support for a common attention-based decision-making process responsible for choice in a variety of domains.

Chronic and acute stress promote over-exploitation in foraging decisions

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Objective: Many real-world decisions concern whether to exploit a current option or search the environment for a potentially better option. Intuitively, such foraging decisions rely not only on the quality of the current option but also the quality of the overall environmental context. This intuition has been captured and formalized in optimal foraging theory where the optimal strategy is to leave a current option when its instantaneous reward rate falls below the long-run average reward rate of the environment. We leverage this computational framework, which has a rich history in behavioral ecology, in order to investigate the modulatory role of affect in human foraging decisions. Stress, in particular, is known to track biologically relevant changes in organisms' environments, leading us to hypothesize that stress would have a characteristic effect on foraging decisions insofar as stress biases evaluations of environmental context.

Methods: We used a virtual patch foraging task in which human subjects foraged for apples among trees of varying quality in a series of orchards. We manipulated the environmental average reward rate across orchards by simulating either a sparse or dense distribution of trees, where new trees took more or less time to find, respectively. Subjects spent a fixed amount of time in each orchard and on every trial decided whether to continue harvesting apples from a current depleting tree or travel to a new unharvested tree. To assess subjects' levels of stress, we independently measured changes in cortisol in response to an acute stress manipulation as well as responses to a perceived chronic stress questionnaire.

Results: On average, subjects adaptively adjusted their leaving thresholds according to changes in environment quality. To test whether individual differences in acute and chronic stress independently predicted the extent to which subjects deviated from this optimal strategy, using regression, we compared subjects' leaving thresholds (relative to optimal) to subjects' levels of stress. Across environment types, we observed greater overexploitation as a function of both cortisol responses and perceived chronic stress scores.

Conclusions:
We find that both acute physiological and chronic psychological stress are associated with a bias toward overexploiting current known resources, suggesting a depreciation of overall environment quality, or equivalently stated, a lower opportunity cost of time. These findings support a computational role of stress in foraging decisions, which might offer a new lens with which to consider other stress-related cognitive and behavioral effects.

Acknowledgements:
This study was funded by the NIH, grant # R01 AG039283.

Psychological and Neurobiological Effects of Food Commercials on Children's Food Choices

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Objective: Children are frequently exposed to food product advertisements that may influence whether they make healthy food decisions. We investigated how food commercial videos influence psychological and neurobiological aspects of children's food choices.

Methods: Twenty-three healthy children between the ages of 8-14 participated in the study. Before functional Magnetic Resonance Imaging (fMRI) scans, they provided separate taste and health ratings for each of sixty food items (30 healthy, 30 unhealthy). Then, during fMRI scans, children made a series of food choices (= eat or not eat) with the same 60 food items after watching food and non-food television commercials in randomized blocks. We compared behavioral and fMRI data between food commercial blocks and non-food commercial blocks.

Results: In our experiment, watching food commercials was not associated with observable changes in children's food decisions (whether to eat or not). However, strikingly, watching food commercials did change the *way* children weigh the importance of taste attribute when making food choices. We fitted a linear regression model of taste and health ratings on children's decisions separately for food and non-food commercial conditions. The decision beta coefficient for taste value was significantly *increased* after watching food commercials compared to non-food commercials ($t = 2.24$, $p < .05$). This change was accompanied by faster decision times during food commercial trials ($t = -2.28$, $p < .05$). Not surprisingly, children did not utilize health values when making food choices in either condition. Preliminary fMRI data analysis showed that right middle frontal cortex activity was significantly decreased when making choices for healthy food items after watching food commercials compared to non-food commercials ($p < .05$, *Small Volume Corrected)*. This fMRI finding in combination with faster choice reaction times after watching food commercials implies that children have reduced self-control after watching food commercials.

Conclusions: Results suggest food marketing can systematically bias psychological and neurobiological mechanisms of children's food decisions. Considering the developmental immaturity of self-regulatory systems in children, as well as pediatric obesity concerns, it is of critical importance to better understand how children make food decisions. A better understanding of how children make food decisions can inform pediatric obesity prevention and treatment.

Modulation of Judgments by Incidental Rewards: Physiological Foundation and Temporal Dynamics

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Objective: Why are all things better on a sunny day? Previous behavioral decision-making research has suggested that people rely on current affective states as informational input to make judgments (i.e. misattribution effects or affect-as-information effects AAIE) even if these feelings are unrelated to judgments (Schwarz & Clore, 1996). In this research, we investigated the physiological foundation underlying AAIE and how affective information is integrated over time. We hypothesized that AAIE are mediated by short-term "physiological spill-over effects" in neurophysiological systems encoding affective reactions. We also hypothesized that the integration of affective information will be attenuated by a long (vs. short) temporal delay between the incidental feeling and the subsequent consumption evaluation, shedding more light on the temporal dynamics of AAIE.

Methods: We conducted three different studies to investigate these questions. In Study 1, participants were instructed that the goal of the study was to investigate their affective reactions to different types of rewards. In each trial they either won or did not win a monetary reward of €15 and then were exposed to either affectively positive or neutral images for 7.5 secs. Participants rated their enjoyment of viewing the images on a 9-point scale. While participants conducted this task, their facial reactions were recorded by a video camera. The video footages were analyzed using an automated facial affective encoding software (FaceReader^{TM}, Noldus Information Technology). In Study 2, participants first participated in a lottery to either win or not win a monetary reward (between-subjects factor). Immediately after the lottery, participants indicated their affective state on a 9-point scale. They then saw in a supposedly unrelated task a series of positive and neutral images and evaluated their enjoyment of viewing them. Next, we introduced a 5-minute, affectively neutral, filler task before they evaluated another series of positive and neutral images. Study 3 followed the same procedure as Study 2, except that the filler task took only 2-minute.

Results: First, we replicated previous findings that winning money significantly increased the reported enjoyment of viewing both positive and negative images in a seemingly unrelated evaluation task (β_{reward}=1.21, p<.001). Facial affective recording captured the "online" integration of affective information, suggesting that these effects can be moved into different directions within subjects on an msec level (t=3.1, p<.002 for positive images and t=2.44, p<.01 for neutral images). Mediation analyses further suggested that facial affective valence served as the physiological basis to explain the causal impacts of affective information on subsequently enhanced enjoyment ratings.

Results from studies 2 and 3 replicated the findings from study 1 that when subjects won money they enjoyed viewing images in an unrelated task more (β_{reward}=3.54, p<.001 in Study 2 and β_{reward}=2.6, p<.01 in Study 3). In addition, we found that both temporal delays (2min and 5min) attenuated enjoyment ratings ($\beta_{duration}$=-4.27, p<.001 for a delay of 5min and $\beta_{duration}$=-5.16, p<.001 for a delay of 2min). Lastly, moderated mediation analyses in studies 2 and 3 found that the causal role of affect due to the incidental reward was attenuated by a 5-minute temporal delay (study 2) but still persisted after a 2-minute temporal delay (study 3).

Conclusions: Incidental affect triggered by winning money influenced the evaluation of unrelated aesthetic experiences in a short period of time. Facial affective reactions indicated that such effects are formally mediated by physiological responses of facial affective valence. Further, AAIE were attenuated by a relatively long but not a short temporal delay, which suggests that the impact of incidental feelings on subsequent evaluations persists only for a short period of time which is in line with the idea that these affects are based on relativity short term physiological spill-over effects of the brain's reward system.

Acknowledgements: This study was funded by INSEAD's research funds.

The precision of preference-based choices depends causally on directional oscillatory phase-coupling from prefrontal to parietal cortex

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Objective: Recent research suggests that preference-based decisions depend critically on neural activity in several widely distributed brain regions. To make a choice one must identify and assign values to the alternatives, then compare these values and finally map them to the objects in space to execute the appropriate actions. Recent brain imaging studies (e.g. M/EEG, fMRI) suggest that the *value to action* transformation critically requires functional coupling between parietal and pre-frontal regions[1–4]. However, due to the purely correlative nature of neuroimaging methods, it was not possible to establish a causal role of functional communication and the associated directionality of the information flow between prefrontal and parietal areas. Here we investigated the causal role and directionality of fronto-parietal oscillatory coupling for preference-based decisions.

Methods: Human participants (n=32) made preference-based choices based on food rewards while receiving transcranial alternating current stimulation (tACS). Crucially, with our novel tACS protocol, we tested both the causality and directionality of fronto-parietal phase-coupling. To achieve this, we independently entrained gamma oscillations in the medial prefrontal (mPFC) and parietal cortex (PC) and manipulated their delay at different angles: $\varphi \square [0\frac{2\pi}{6}, 1\frac{2\pi}{6}, 2\frac{2\pi}{6}, 3\frac{2\pi}{6}, 4\frac{2\pi}{6}, 5\frac{2\pi}{6}]$. If choice behaviour is modulated by the phase of synchronized oscillations over both sites, then choice-accuracy should be explained by a sinusoidal parametric model (as a function of the delay between the fronto-parietal tACS oscillations).

Results: Choice accuracy is well captured by a sinusoidal model (fitting the data better than a single-constant or linear model). Anti-phase stimulation significantly reduced the preference-based choice precision relative to both sham ($T(31)=2.5$, $P=0.008$) and full in-phase stimulation ($T(31)=1.9$, $P=0.03$). The maximum precision in choices occurred at $\varphi = 1\frac{2\pi}{6}$, with a highly significant difference to anti-phase stimulation ($T(31)=3.74$, $P<0.001$). Critically, the estimation of the oscillatory difference between the two regions revealed that the mPFC phase leads with respect to PC phase by 24°±15°.

Conclusions: Our results reveal that the precision of preference-based choices depends causally on fronto-parietal coupling of brain activity in the gamma-band. Crucially, we show that this information flows from mPFC to PC. These results support the idea that mPFC to PC oscillatory coupling is required to adequately map values (represented in mPFC) to the neural representations of objects in space (represented in parietal cortex) in order to execute the appropriate actions.

1. Hunt, L. T., Dolan, R. J. & Behrens, T. E. J. Hierarchical competitions subserving multi-attribute choice. *Nat. Neurosci.* 17, 1613–22 (2014).
2. Polanía, R., Krajbich, I., Grueschow, M. & Ruff, C. C. Neural oscillations and synchronization differentially support evidence accumulation in perceptual and value-based decision-making. *Neuron* 82, 709–720 (2014).
3. Boorman, E. D., Behrens, T. E. J., Woolrich, M. W. & Rushworth, M. F. S. How green is the grass on the other side? Frontopolar cortex and the evidence in favor of alternative courses of action. *Neuron* 62, 733–43 (2009).
4. Hare, T. A., Schultz, W., Camerer, C. F., O'Doherty, J. P. & Rangel, A. Transformation of stimulus value signals into motor commands during simple choice. *Proc Natl Acad Sci U S A* 108, 18120–18125 (2011).

Testing Salience Theory of Risky Choice Using Eye-Tracking and Behavioral Data

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Objective: Most models of economic choice assume that risk preferences are stable across different situations and are thus *context-independent*. Yet a large body of evidence shows that people exhibit both risk-averse and risk-seeking behavior, depending on the environment. Such context-dependent behavior can be explained by a recent behavioral theory of decision-making where salient features of risky lotteries are overweighted (Bordalo, Gennaioli, Shleifer, 2012). The key assumption of this theory is that salience depends on value-based properties of lotteries, which we refer to as "cognitive salience." While this theory can explain several features of risky decision-making, its core assumption has not yet been tested. We provide several tests of this theory by using a combination of eye-tracking and behavioral data.

Methods: We first used eye-tracking to measure the extent to which the "cognitively salient" features of lotteries affect how people process the information presented in lotteries. Sixteen subjects made a series of choices between a risky lottery and a sure option. We paid subjects a $5 participation fee plus an outcome of one randomly chosen trial, with upsides as large as $2040. Next, we recruited two-hundred Amazon MechanicalTurk subjects to choose between the same pairs of lotteries, while we increased the visual salience of the feature that is predicted to be most cognitively salient. We hypothesized that manipulating visual salience would amplify the effects of cognitive salience.

Results: Our results are largely consistent with the predictions of salience theory: subjects exhibit both risk-seeking behavior and risk-averse behavior depending on the choice set and the observed choice probabilities are sensitive to the decision values generated under salience theory. We then structurally estimate parameters of both salience theory and prospect theory and compare the explanatory power of each. Our eye-tracking data shows that for trials in which losses are salient, subjects look significantly less at losses than at other information. When we exogenously increase the visual salience of a "cognitively salient" lottery outcome, we find that the context-dependent choice effects are significantly magnified.

Conclusions: We replicate the well-known result that risk preferences are unstable across environments. Using a computational model of risky choice, we then show that the data support sharp predictions of salience theory. Using eye-tracking data, we perform a novel test of the core assumption and find support that attention is allocated to salient states of the world. Finally, we show that exogenously manipulating the visual salience of lottery outcomes can have a significant impact on behavior.

Status, Risk, and Catching Up

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Objective: Other-regarding behavior in decision-making under risk remains relatively unexplored in experimental economics. To extend research in this particular direction, we focus on the role of other-regarding concern in making risky decisions which is captured through the effect of status, as defined by the relative distribution of wealth.

Method: We design an experiment to test whether individuals' risk preferences changes when their status (relative wealth distribution) varies. In a simple experimental design we study subjects' risk preferences where we vary subjects' status while keeping their absolute wealth unchanged.

Results: Findings from the experiment provide evidence that people behave differently in making decisions under risk when they are standing at different points in the relative distribution of wealth.

Conclusions: The next step of this research is to collect neuroimaging data to better understand the pathways through which status affects the willingness to bear risk.

Risk preferences in a competitive social context

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Objective: Many real life decisions are influenced by the states and actions of others. However, the bulk of decision making research paradigms, with the notable exception of work by Steinberg and colleagues (2005), assess risk in isolation. We sought to develop an ecologically valid task that captured social influences on individual risk preferences.

Method: Subjects were recruited in groups of varying size to perform social and non-social variants of the Balloon Analogue Risk Task (BART). Here, we describe a traditional non-social BART as well as a novel social extension, the competitive BART (cBART). The traditional BART was performed alone and required subjects to fill a virtual balloon for monetary rewards. Subjects accrued money with every pump and had the option to bank their earnings by cashing in at any time. Each balloon had a set maximum limit to which it could be pumped; balloon limits were drawn from a uniform distribution. If a balloon's limit was reached, it would explode and result in the loss of any earnings. The cBART differed from the BART in that it was played with another subject, who was identified with a photo. During the cBART, subjects viewed their opponent's balloon, in real-time, next to their own. Subjects received their cashed-in earnings only if their trial earnings exceeded or were equal to their opponent's; an exploded balloon or balloon cashed in below an opponent's reset a subject's earnings to zero. Half of the subjects performed the tasks with a timer, in which any earnings not cashed-in before ten seconds were lost; the other half had unlimited time to complete each trial.

Results: We employed a multilevel model to investigate the effects of time-constraint and BART version on number of pumps. No main effect of time-constraint or BART version was found, but a significant interaction between the two factors was. Post-hoc paired t-tests indicated that the number of pumps increased significantly from BART to cBART in the no-timer condition, but the number of pumps did not significantly differ between BART versions when there was a time constraint.

Conclusions: Together these findings indicate that risk-related behavior is significantly affected by others, and that this influence may only arise when individuals are given enough time to interact with and react to others. This finding could be interpreted as counter to the commonly held belief that social modulation of choice behavior is driven by impulsivity; instead, social effects on decision making may require adequate time for the development of a social context.

Neuroanatomical Correlates of Delay Discounting in Adolescents

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Objective: As a behavioral measure of impulsivity, delay discounting (DD) has been linked to risk taking behaviors and substance misuse, which are a particularly acute source of morbidity and mortality during the critical period of adolescence. Most prior work has focused on the functional neural correlates of DD (Kable & Glimcher, 2007). Some work has looked at anatomical brain features predictive of DD, identifying frontal regions where gray matter volume correlates inversely with impulsivity (Bjork et al. 2009). Here we examined neuroanatomical correlates of DD in a sample of adolescents. Further, we searched for candidate neural mediators of the relationship between cognitive ability and DD (Shamosh & Gray 2008).

Methods: We examined the relationship between gray matter volume and discount rates (DRs) in 430 subjects, age 17.1± 3.2. Cognition was assessed for each subject using a computerized neurocognitive battery. T1 images were acquired for each subject at 3T with a resolution of 1.0 x 1.0 x 0.9mm. We obtained an accurate estimate of gray matter volume on a voxelwise basis from T1 images. General linear models were used to examine the effect of DD and cognition while adjusting for age, sex, and presence of psychiatric symptoms. Type I error was controlled using cluster correction ($z>2.30$, corrected $p<0.05$).

Results: DD was inversely related to complex reasoning (CR) ability, as previously reported. Whole-brain analysis revealed several regions where volume correlated *negatively* with DRs. Higher DRs—indicative of impulsivity— were associated with diminished gray matter volume in a network of regions including the precuneus, dorsolateral prefrontal cortex (DLPFC), orbitofrontal cortex, ventromedial prefrontal cortex, and temporal areas. In contrast, CR was *positively* correlated with volume in multiple brain regions, consistent with previous reports (Haier et al. 2004). Notably, clusters in DLPFC and temporal pole showed partial overlap with clusters where volume correlated negatively with DRs.

Conclusions: We identify novel neuroanatomical correlates of DD in a unique sample of adolescents. These correlates include several regions previously associated with valuation (medial frontal regions) and more generally with the default-mode network (temporal areas, precuneus). In a subset of these regions (DLPFC and temporal pole), the overlap and directionality of effects suggest that individual differences in brain structure may mediate the relationship between discount rates and CR.

Distinct prefrontal mechanisms underlying magnitude influences on the evidence for perceptual and value-based decisions

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Objective: Goal-directed behavior involves making decisions based on perceptual information about the environment or preference-related information about the value of choice options. Neuro-computational theories suggest that both types of choice depend on computations that accumulate the difference of sensory or value information about the choice alternatives. However, magnitude –a crucial dimension of the choice process– is often ignored in such models. Recent research indeed suggests that value-based decisions may also be affected by the absolute reward magnitude (not just the absolute difference) of the choice alternatives; however it remains unclear whether similar or distinct brain mechanisms mediate such magnitude influences on evidence computations in perceptual and value-based decisions.

Methods: We employed fMRI in 35 participants during a behavioural paradigm where perceptual and value-based choices were based on identical stimuli and motor responses, so that decisions reflected selective accumulation of just one type of evidence. To characterize the mechanisms by which stimulus magnitude influences perceptual and value-based choices, we implemented a computational dynamical model that parsimoniously estimates the effects of different levels of stimulus evidence and magnitude on participant- and condition-specific choice accuracies and reaction times.

Results: We found that distinct structures of the human prefrontal cortex – the left-superior-frontal-sulcus and ventro-medial prefrontal cortex – specifically weight the trial-by-trial evidence by its associated magnitude during perceptual and value-based choices, respectively. Moreover, increasing magnitude affects the two types of evidence with a differential sign, by reducing or enhancing sensitivity for perceptual and value-based choices, respectively.

Conclusions: This functional and anatomical dissociation suggests that the human brain has evolved functionally distinct mechanisms that represent the magnitude-weighted evidence for choices based on perceptual or value information. Our findings have implications for neuro-computational theories of decision making and they provide important hints to the origins of puzzling distortions encountered in economic choices.

A dynamic threshold model of optimal stopping

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Objective: Optimal stopping theory is concerned with problems of timing to take actions. Our objective is to develop and test a class of threshold models that update information using collected observations under a normal-distribution variation on the traditional stopping problem. Intelligence, working memory and risk attitude are examined as potential drivers of the performance.

Methods: 120 subjects participated in a rewarded experiment. Each subject completed the optimal stopping task with thirty different sequences and questionnaires measuring intelligence (Raven's matrices and Cognitive Reflection Test), working memory (Digit span and Free recall working memory test) and risk aversion (Holt & Laury Test). We run 100.000 simulations and computed the average gain of main decision rules from the literature (cutoff, candidate count and successive non-candidate rules) and the new class of threshold models. We measure the fitness of each decision rule as the fraction of choices selected by a subject according to the model and we compare the models using behavioural data. Additionally, we cluster participants according to questionnaires' scores to identify possible drivers of performance.

Results: Under the conditions of our choice problem all the class of threshold models outperforms the rules described in the literature. The cutoff-threshold rule fits behavioural data better than both the benchmarks and shows a clear exploration/exploitation tradeoff. Results highlight the importance of learning from previous observations and the role of intelligence as major predictor of performance, measured both as value earned and precision of the model adopted, whereas risk attitude and working memory show no significant predictive power. Subjects with an high score in Raven's test adopt more often the cutoff-threshold model and choose higher values. The higher performance can be explained by the ability to better estimate the unknown parameters.

Conclusions: Newly introduced cutoff-threshold model fits behavioural data better than all already studied decision rules. Higher performance in the intelligence test is correlated with higher average gain and frequency of adoption of this model.

Acknowledgements:
This study was funded by the ERC, grant # 617629.

Neural Mechanisms Promoting Selflessness in Potential Conflicts of Interest

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Conflicts of interest (COI) pose a challenge to social harmony, yet some people pursue righteous actions when confronted with such dilemmas. Whereas some scholars have suggested that righteousness is relatively automatic and inherently rewarding, others have suggested that neglecting one's self-interest involves effortful control. We used fMRI to gain insight into the neural correlates of righteousness when facing conflicts of interest.

Participants completed a judgment task while undergoing fMRI. On each trial, a display of 100 dots appeared with a line dividing the left and right halves. Although participants were instructed to indicate which side contained more dots accurately, they were paid more ($0.10/response) when they indicated there were more dots on the right than when they responded there were more dots on the left ($0.02/response). Ambiguity about the correct response was manipulated such that half of the trials involved easy and half involved difficult discriminations. On trials with more dots on the left side, participants may be tempted to abandon their obligation to be accurate and provide the response offering the larger financial incentive. This temptation should be especially pronounced when the correct response is ambiguous, as lucrative responses can be more flexibly categorized as honest mistakes instead of selfish actions.

We find that incentivized errors occurred more often than disincentivized errors ($F(1,25) = 12.46$, $p = .002$). There was an interaction between ambiguity and incentives in shaping responses ($F(1, 26) = 13.02$, $p = .001$) as incentivized responding was higher when the correct response was relatively more ambiguous compared to when it was relatively less ambiguous ($t(26) = 4.88$, $p < .001$). Yet the extent to which participants allowed the COI to bias their judgment as the proper response became more ambiguous varied across individuals. fMRI analyses revealed that individuals who responded accurately despite the COI recruited greater activation in dorsolateral prefrontal cortex and other regions implicated in self-control. Importantly, activation in putative reward regions did not predict individual differences in behavior.

Whereas some have posited that ethical behaviors are automatic and do not require control to enact, the current results indicate that individual differences in the recruitment of prefrontal control regions predict eschewing personal gain in COIs. In light of the present findings, interventions seeking to limit the negative consequences of COIs should focus on enhancing self-control among those whose judgments they seek to insulate from self-interest or by reducing ambiguity in potential COIs.

Acknowledgments: This research was conducted and funded, in part, while M.F.M. was a Visiting Scholar and recipient of the Dean's Emerging Leader Award at the Rotman School of Management, University of Toronto. This research was financed, in part, through a seed grant from the Desautels Centre for Integrative Thinking, Rotman School of Management, University of Toronto and an Insight grant from the Social Sciences and Humanities Research Council of Canada (SSHRC) both awarded to N.M. The authors would like to thank L. Catenacci, J. Chun, R. Dyer, L. Fagin, L. Nind, and E. Wiley for assistance with data collection.

Stimulating impulsivity: does Subthalamic Nucleus Deep Brain Stimulation affect Intertemporal decision making in Parkinson patients?

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Objective: Deep brain stimulation (DBS) of the Subthalamic nucleus (STN) is a widely accepted treatment for the motor symptoms of Parkinson's disease (PD). In general, PD patients have an increased tendency to develop impulse control disorders (ICDs). Although STN-DBS is successful in decreasing the motor symptoms of PD, cognitive side-effects remain elusive and both attenuation as well as development of ICD symptoms after DBS onset was reported. In addition, previous studies have found that DBS can alter activity in areas connected to the target structure. Several areas involved in reward valuation, such as the prefrontal cortex and striatum, are linked to the STN, and thus activity in these areas might be affected by STN-DBS. It is therefore likely that STN-DBS alters valuation processes and as a consequence, decision behavior. We investigated the effect of STN-DBS on impulsive decision making.

Methods: We tested 40 Parkinson patients receiving STN-DBS treatment for at least 3 months, during their regular check-up at the University clinic in Düsseldorf. Patients with no severe depression and no indication of dementia were included. Patients were pseudo randomly assigned to one of four groups, to test DBS on/off states as well as medication on/off states between subjects. Stimulation was turned off at least 50 minutes before testing in the DBS-off state, whereas patients in the medication-off state did not receive medication for at least 12 hours before testing. States were verified using the Unified Parkinson's disease rating scale (UPDRS). We used an intertemporal choice task in which patients chose between smaller, sooner available and larger, later available monetary amounts to measure their individual discounting rate, which has been shown to be increased in persons with ICDs.

Results: UPDRS scores showed a significant difference in motor state between the on- and off DBS groups, but no significant difference in on- and off-medication groups. Patients receiving STN-DBS did not choose more or less impulsively compared to the off-DBS group.

Conclusions: We did not find evidence for an effect of STN-DBS on choice impulsivity. However, our results need to be treated with caution due to the relatively small sample size.

Verbal Descriptions of Others' Ability Corrupt Avoidance Learning from Observing their Behavior

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Objective: Observational avoidance learning – attaining information about what to avoid through observing others – can be safer and more efficient than individual learning. Observational information should, however, be used flexibly as a function of the ability of the observed demonstrator, for instance to avoid copying non-adaptive behavior. Information of a demonstrator's ability can be gained both indirectly through verbal description and more directly by observation of actual behavior. Here, we investigated how the interaction of described and actual ability of the demonstrator influenced behavioral performance during an observational avoidance learning task.

Methods: Forty-three subjects learned a sequential two-choice task to avoid shocks. They both performed the task themselves and observed two demonstrators that performed the same task. Subjects were divided into two groups that were told that the demonstrators were either high performers (Described-High) or low performers (Described-Low). In fact, in both groups, one demonstrator had a high ability (Actual-High) and the other behaved randomly and thus had a low ability (Actual-Low) to learn. Behavioral data were analyzed using logistic mixed models and reinforcement learning models. As physiological indices of learning, we measured skin conductance responses (SCRs) and pupil dilation.

Results: Behavioral data showed that verbal information influenced subjects' performance such that the Described-High group performed better than the Described-Low group. Furthermore, the verbal description of demonstrator ability interacted with the actual ability resulting in worst performance during observation of the Actual-Low demonstrator when correctly described as a low performer. Analyses of pupil dilation and behavioral data suggested that the verbal description of demonstrator ability influenced performance by affecting attention directed towards the observational information. In addition, both pupil dilation and SCRs during observation of the demonstrators' choices provided psychophysiological measures of learning.

Conclusions: Verbal description of a demonstrator's learning ability as low corrupts observational avoidance learning. In particular, the verbal description interacts with the actual ability of the demonstrator, so that observational learning is most impaired when the actual ability to learn is low, although the description then is correct. We suggest that this effect is partly due to a decrease in attention.

Acknowledgements:
This study was funded by the European Research Council, grant 284366 (ELSI), to A. Olsson.

The Striatum Multiplexes Distinct Reward Signals

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Abstract: A wide range of rewards—from monetary incentives to praise from a supervisor—shape our behavior and contribute to the substantial variability observed across the population. To study the neural underpinnings of reward processing, researchers have employed various paradigms that isolate responses associated with the receipt of reward. In one popular paradigm, participants are presented with a card and asked to guess whether the number on the card is higher or lower than the number five (Delgado et al., 2000). When participants guess correctly, they gain money; but when participants guess incorrectly, they lose money. Comparing responses to gains relative to losses has revealed widespread activation across the striatum in multiple populations, including healthy adults (e.g., Hariri et al., 2006), adolescents (Forbes et al., 2009), and older adults (Cox et al., 2008). Yet, these canonical observations may obscure other, unidentified relationships between reward and the striatum. Indeed, the striatum is composed of multiple interacting functional subunits that are difficult to examine using standard neuroimaging resolution (e.g., 3.5 cubic mm voxels) and analytical approaches that do not take into consideration how distinct spatiotemporal responses. To investigate this issue, we measured striatal responses using high-resolution neuroimaging (1.8 cubic mm voxels) in participants (N = 22) playing the card task. We quantified the spatiotemporal responses to monetary gains and losses using tensorial independent component analyses (Beckmann & Smith, 2005) and dual-regression analysis (Smith et al., 2014). Consistent with prior work using the card task, we found one spatiotemporal component within the striatum that exhibited an increased response to gains (relative to losses). Strikingly, we also observed another spatiotemporal component within the striatum that exhibited increased responses to losses (relative to gains). Our findings demonstrate that the striatum multiplexes distinct reward signals: monetary gains and losses are simultaneously represented by distinct spatiotemporal response patterns within the striatum. These observations highlight how advanced analytical approaches in neuroimaging can enhance knowledge about the spatiotemporal contributions of regions such as the striatum to reward processing.

Acknowledgments: This study was funded by National Institutes of Health grants R01-MH084081 (to MRD) and F32-MH107175 (to DVS).

Decomposing Self-Control Using a Novel Eyetracking Task: Individual Differences in Goal Pursuit Despite Interfering Aversion, Temptation, and Distraction

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Background
Self-control is associated with life satisfaction, positive affect, and social competencies (Gailliot et al., 2007). Conversely, not having any self-control is linked to psychiatric disorders such as addiction (Bechara, 2005; Buehringer et al., 2008), and attention deficit hyperactivity disorder (Schweitzer et al., 1995). Currently most research in the area relies on self-report. Here we developed a new paradigm testing three domains of self-control in one task using aversive, tempting, and neutral picture-distractors. The aims of the study were (1) to develop a novel task of self-control, (2) to decompose self-control into three central aspects: bearing aversiveness, resisting temptations and ignoring neutral distractions.

Methods
The final sample consisted of 116 participants (51 male, mean age 25.89, *SD* = 3.80). The task required participants to attend to a cued target location while disgusting, erotic and, neutral pictures were presented as distractors. At the target location, a briefly presented target letter “E” or “F” is presented. The task is to identify the letter and respond by button press. Behavioral and eyetracking data were obtained during the performance of the task. After task completion, a lottery took place, in which one trial was randomly selected. If participants had responded correctly and within 1000 ms on the selected trial, they received 10 Euro. Additionally to our novel task, self-reported self-control was assessed and participants performed a color Stroop task, an unsolvable anagram task and a delay of gratification task using chocolate sweets.

Results
We found that aversion, temptation, and neutral distraction were associated with significantly increased error rates, reaction times and gaze pattern deviations. Overall task performance on our novel task correlated with self-reported self-control ability. Measures of aversion, temptation, and distraction showed moderate split-half reliability, but did not correlate with each other across participants. Additionally, participants who made a self-controlled decision in the delay of gratification task were less distracted by temptations in our task than participants who made an impulsive choice. This was reflected in higher gaze distance from target location during presentation of erotic pictures as compared to neutral pictures.

Conclusion
Our data suggests that (1) our novel self-control task is a valid measure of trait self-control, (2) bearing aversiveness, resisting temptations and ignoring neutral distractions are central and independent aspects of self-control.

Decreasing inequality aversion with non-invasive brain stimulation

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Objective:

Economic inequality in society has been associated with various negative consequences, including reduced economic growth, reduced happiness, and increased drug abuse. Neuroimaging studies have revealed that distinct forms of income inequality are processed in the lateral prefrontal cortex (LPFC). It is unclear how the information processed by this brain area relates to choice in situations presenting different types of inequalities. Here we used transcranial direct current stimulation (tDCS) over the right LPFC to investigate if altering its neural activity differentially influenced choice in disadvantageous inequality situations (i.e. where the person deciding is worse off) compared to advantageous inequality situations (i.e. where the person deciding is better off). Based on previous tDCS findings, we hypothesized that increasing this activity by means of anodal tDCS should make participants less inequality averse in both advantageous and disadvantageous decisions. The opposite behavioral pattern was expected when decreasing rLPFC excitability with cathodal tDCS.

Methods:

Participants (N = 72) were randomly paired with a partner in the lab. While the partner awaited the end of the session in a separate room, participants performed a modified version of the ultimatum game while receiving either anodal, cathodal, or sham tDCS. In each trial, participants were required to accept or reject offers that split 40 Swiss Francs (CHF) between them and their partner. Pay splits varied in increments of 4 CHF, giving 5 levels of advantageous inequality and 5 levels of disadvantageous inequality.

Results:

As expected, we found a significant decrease ($p = 0.03$) in disadvantageous inequality aversion in participants who received anodal tDCS compared to participants who received cathodal or sham stimulation. By contrast, we found no difference between the cathodal and the control group ($F < 1$), possibly due to a ceiling effect. Further, we did not observe any effect of tDCS on advantageous inequality aversion ($F < 1$).

Conclusions:

Our results suggest that neural activity in the right LPFC is causally necessary for moderating aversion to disadvantageous inequality. Intriguingly, tDCS effects were more pronounced in disadvantageous inequality than in advantageous inequality, suggesting that different mechanisms may be implementing inequality aversion depending on which party is benefitting from unequal situations.

Testing the causal influence of vasopressin on cooperation and altruistic punishment: a randomized intranasal administration study

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Cooperation among genetically unrelated individuals is common among humans. Recent experimental findings suggest that a possible account is the prevalence of altruistic punishment: human's willingness to pay a cost for the sake of punishing non-cooperators. The current study examined the role of Arginine Vasopressin (AVP) – a neuropeptide known to modulate a wide range of mammalian social behaviors such as bonding, affiliation, social recognition and aggression - on altruistic punishment and punishment-induced cooperation in humans. Sixty-four healthy young males received either intranasal AVP or placebo in a randomized, double-blind manner and took part in two treatments of the public good game: with and without punishment. AVP had no impact on either punishment or cooperation rates in the public good game. Our results therefore argue against a modulatory role of AVP on altruistic punishment in humans, although we post-hoc found several interesting patterns in the data that may worth future exploration.

Model Based vs. Model Free Learning: Who's Controlling the Controller?

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Objective: Humans update the values underlying their choices in two different ways: In model-free (MF) reinforcement learning, past reward outcomes lead to an increased probability to repeat associated actions, whereas in model-based (MB) reinforcement learning, a model of the contingencies between states of the world, actions, and outcomes is updated to guide choice. Both types of learning have been shown to involve separable neural processes. But how do these parallel systems work together when both supply valuable predictions for future choice? A recent study (Lee, 2014) proposed that this is achieved by a weighted selection based on each system's current reliability in a given context. Here we want to deliver causal evidence for such a neural implementation and further clarify the biological mechanism guiding arbitration between learning systems. To achieve this, we used transcranial direct current stimulation (tDCS) over a lateral prefrontal cortex (lPFC) site previously shown to encode the reliability of both MF and MB learning systems.

Methods: 55 healthy subjects received neuronavigated tDCS over the left lPFC, using either an excitatory anodal, suppressive cathodal, or sham stimulation protocol. Each subject performed two sessions of a probabilistic two-step decision task to collect real monetary rewards. Using a mixed within-between design, we applied the different types of tDCS to the three groups for the whole second session of the task. Parameters corresponding to preference for one system and arbitration between systems were estimated by fitting a model to the choice data, thereby dissociating between MB and MF learning over time.

Results: Compared to sham, subjects receiving anodal tDCS (locally increasing neural excitability) exhibited more pronounced MB learning, while cathodal tDCS (decreasing excitability) led to increased MF learning after its application. Consistent with previous proposals, this suggests that the stimulated region may favor MB learning by inhibiting the MF system when its predictions are less reliable. Moreover, tDCS interfered with the arbitration between MB and MF learning systems itself, as switching frequency between the two systems was increased during anodal and decreased during cathodal stimulation.

Conclusions: Our results deliver causal evidence that a prefrontal arbitration mechanism governs the interaction between MB and MF reinforcement learning systems. Our study also demonstrates that it is possible to enhance MB learning using neurostimulation, which could be an important step towards future clinical applications to psychiatric diseases linked to dysfunctional goal-oriented behavior.

Lee, S. W., Shimojo, S., & O'Doherty, J. P. (2014). Neural computations underlying arbitration between model-based and model-free learning. *Neuron*, *81*(3), 687-699.

Hierarchical hidden Markov modeling of real time changes in strategic behavior in a game theoretic context

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Objective: In a dynamic environment in which players are continuously interacting in a competitive game, these players must generate flexible strategies that can adaptively respond to their opponent's actions in real time. Consider a two-player soccer match in which a kicker's objective is to dribble a ball into a goal, while a keeper's objective is to block the ball. Players must continuously update decisions to employ winning strategies. Because strategies are being adaptively adjusted in real time, it is difficult to determine precisely which strategy is being utilized at any given time. Hence, parsing updates to decision-making throughout the task becomes a challenge.

Methods: We use a hierarchical hidden Markov model (HHMM) in which high-level states represent subjects' current strategies and low-level states represent current behavior. Sequences of high-level states are used to identify global patterns concisely summarizing entire gameplay sequences, while specific behavioral states making up a given sequence can be identified as the strategy currently employed. We applied this approach to the aforementioned two-opponent game played by rhesus macaques.

Results: The HHMM discovered 4 different global patterns of behavior. More importantly, it identified when changes in behavior or transitions to another strategy occurred as players updated their movements. This approach reveals highly nuanced and sophisticated strategies in non-human primate interactions within a competitive game setting, requiring theory of mind capabilities and awareness of others' intentions and strategies. Additionally, we are currently analyzing neural activity, as well as effects of muscimol inactivation in the DMPFC and DLPFC, on decision-making during the task.

Conclusion: Our results demonstrate a novel application of HHMM in a free range decision-making task, making possible the identification of current strategies implemented throughout each continuous sequence of a trial. This approach may also serve to generate effective predictors of neural activity in higher-level brain areas, as we are currently investigating. In conclusion, the study provides a novel paradigm for investigating the neural circuitry underlying real-time behavior and strategies in game theoretic contexts.

Acknowledgements: CIHR Doctoral Award 84765, NIMH Grant MH086712, Simon's Foundation Autism Research Award 304935

Market Experience Attenuates the Endowment Effect through Modulation of Anterior Insula: A Training Study

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Objective: Consumers ask a greater price for goods that they own than they are willing to pay for otherwise identical goods, a phenomenon known as the endowment effect. Previous fMRI research indicates that lower insula activity during selling is related to a reduced endowment effect in experienced compared to inexperienced traders. The present study tests whether experimentally manipulated market experience reduces the endowment effect through decreasing insula activation.

Methods: Inexperienced traders (n=13) made trading decisions while undergoing fMRI before and after the treatment of short-term selling experience. In a pretest session prior to market experience, and in a posttest session after the market experience treatment, participants made a series of decisions to buy or sell products at high and low prices during neuroimaging. Between the two scanner sessions, participants were given incentives to trade consumer goods on eBay over the course of two months.

Results: Trading experience reduced both the endowment effect behaviorally ($p<0.01$), and right anterior insula activation when presented with lowball offers during selling ($p<0.05$). Moreover, the change in insula activity during low selling offers positively predicted the change in endowment effect, and partially mediated the effect of trading experience.

Conclusions: These results provide causal evidence that selling experience reduces the salience of selling at a loss, consistent with behavioral evidence that market experience attenuates economic biases.

Acknowledgements:
This project was made possible through the support of the University of Chicago Wisdom Research grant, funded by the John Templeton Foundation. The opinions expressed in this project are those of the authors and do not necessarily reflect the views of the John Templeton Foundation.

Timing of value representation in ventromedial prefrontal cortex in a complex auction task

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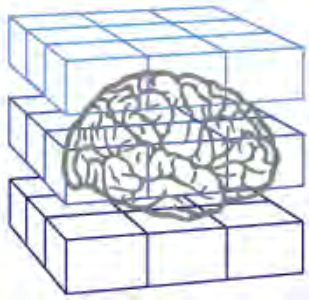
Objective: The involvement of the ventromedial prefrontal cortex (vmPFC) in value-based decision-making is well established (Bartra et al., 2013). However, prior investigations of vmPFC function have generally involved multioption choice or simple rating tasks. It is therefore unknown whether neural activity in vmPFC reflects value in more complex decision-making tasks, such as bidding in auctions. The involvement of vmPFC in such tasks is not a foregone conclusion, especially since behavioral experiments suggest that bidding may involve different psychological processes from choices and ratings (Lichenstein & Slovic, 1971). Here we test whether and when neural activity in vmPFC reflects subjective value during an intertemporal bidding task.

Methods: Forty participants (16 males) participated in the functional magnetic resonance imaging study. In the scanner, subjects selected the amount they would be willing to receive in exchange for a fixed amount of $75 at a variable delay (e.g., "I feel indifferent between receiving $75 in 28d and receiving $? now"). Bids were entered using an interface that allowed subjects to scroll through possible values. We analyzed our neuroimaging data with a general linear model with separate regressors representing the subjects' bid (our estimate of their value of the delayed outcome) at different points in the bidding procedure (when the question was asked; the beginning, middle and end of the response period).

Results: We found that neural activity in vmPFC was correlated with the subject's bid, but only at the end of the bidding procedure – that is, at the end of the response period when the participants submitted their answer. Contrary to expectations, we did not find a representation of value in vmPFC at any earlier time points in the task (question period, beginning and middle of the response period).

Conclusions: We find that vmPFC activity reflects value at the end of a bidding task in the same manner as it does in simpler choice tasks. The timing of this activity suggests that subjects do not have well-formed values at the onset of bidding – rather, values are not fully crystallized until the time a response is submitted. The lack of well-formed values at the onset of bidding is consistent with psychological phenomena such as anchoring and adjustment; further, it suggests that values are constructed, and therefore potentially malleable, during the process of bidding.



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Session V
Finance and Aging

Adult age differences in the influence of financial skewness on choice and neural activity

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Objective: Although neuroeconomic research on the processing of the variance or risk of the outcome of a decision continues to grow, less attention has been paid to skewness. Skewness may be even more important to study in old age, when individuals are disproportionately targeted by investment fraud attempts that promise rare opportunities for high returns. Here we examined age differences in choice and neural activity while individuals chose to accept or reject symmetric, positively skewed, or negatively skewed risky gambles.

Method: In a healthy adult life-span sample (N = 34; M_{age} = 47.91, $Range_{age}$ = 18–85), this study focused on the interaction between age and valence (positive or negative skew) on both acceptance rates and neural activity when presented with skewed gambles. While undergoing fMRI, participants chose to accept or reject either a symmetric (50% chance of modest win or loss), negative-skew (25% chance of large loss), or positive-skew (25% chance of large gain) gamble on each of 72 trials. The alternative ("reject") was always a certain $0. Participants were paid in cash at the end of the session based on the outcome of a subset of their choices.

Results: Analysis of behavioral data revealed an age by valence interaction in acceptance rates. Follow-up analyses clarified that older adults were less likely to accept negatively skewed gambles than younger adults, as well as a non-significant age difference in acceptance of positively-skewed gambles. Whole-brain analysis of fMRI data also revealed an age by valence interaction in neural activity in the left dorsolateral prefrontal cortex (dlPFC) and left inferior frontal gyrus (IFG). Follow-up analyses revealed that older compared to younger age was associated with greater signal change in these regions during negative-skew trials and less signal change in these regions during positive-skew trials. A priori region of interest analyses also revealed a main effect of age in the nucleus accumbens (NAcc), with age being associated with less signal change in this region, but no significant interactions in this region.

Conclusions: The behavioral findings suggest that age influences the willingness to accept negatively skewed gambles. The neural findings suggest that age-related differences in recruitment of the lateral frontal cortex may differentially influence the likelihood of taking skewed risks. Future analyses will explore how connectivity between lateral frontal regions and medial frontal and ventral striatal regions may differentially influence choice at different ages.

Acknowledgements: This study was supported by grants from the Financial Industry Regulatory Authority Investor Education Foundation and National Institute on Aging (R00-AG042596).

Character count: 2193

(Emotional) Reference Point Formation

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Objective: Reference points influence investor behavior because financial outcomes are coded as gains or losses relative to the reference point. The literature mentions multiple reference points, such as the purchase price or historic highs. However, it is not clear how exactly reference points are formed or "how multiple reference points compete and combine" (Kahneman, 1992). Here, we use eye-tracking to examine how people form their reference points. In addition, we investigate how incidental emotions affect reference point formation. Recent literature has shown that emotions influence financial decisions at the market level (e.g., Edmans, Garcia, and Norli 2007) but little is known about the underlying mechanism.

Methods: 22 subjects participated in an eye-tracking study. Incidental emotion was induced by showing either a happy, frightening, or emotionally neutral control video. After watching the video, subjects viewed stock charts and were asked to determine their "neutral selling price", i.e., reference point (Baucells, Weber, and Welfens 2011). Eye-tracking was used to examine the extent to which people looked, i.e., considered, the purchase, current, high, and low trading prices on the stock chart as they formed their reference points.

Results: Our eye-tracking data shows that, as subjects form their reference points, the purchase and current price receive most attention, followed by highs, while lows receive very little attention. We found that incidental emotions significantly influence reference point formation: relative to those experiencing positive emotions, investors experiencing negative emotions form significantly lower reference points. Our eye-tracking data reveals that incidental emotions influence how investors allocate their attention to stock charts: investors in the negative condition focus primarily on the current price, whereas those in the positive condition focus on the purchase price.

Conclusions: This research shows that investors mostly consider the purchase and current price when forming their reference points. At the same time, incidental emotions influence how they allocate their attention to financial information, and as a result, this differential attention allocation affects their reference points. These findings have implications for individuals' financial decision-making and help us better understand various market level phenomena, such as the disposition effect.

A novel stock market task to investigate the neural underpinnings of financial decision making in rats

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Objective: Market crashes have devastated economies since the very first recorded price bubble crazed Dutch tulip investors in 1637. Such irrational behavior is elicited when escalating prices bias individuals' expectations about an asset's future payoffs. Yet, the neural valuation mechanisms facilitating investors' choices are not well understood. Rodent models of risky decision-making represent a critical means of interrogating the evolutionarily conserved reward circuits without confounding 'high-order' factors (e.g. numeracy). To this end, we have developed a stock market task for rats.

Methods: In our task, cohorts of 4 adult rats nosepoke in holes to select and subsequently buy, sell, or hold virtual assets that determine the levels of sweet liquid reward earned. The rats are placed in four separate operant chambers with five nosepoke holes located on one wall. Available assets are indicated via blinking LED lights recessed in the nosepoke holes, with the blink rate proportional to the volume of shares of a given asset currently being held by all 4 rats. Rats begin a trial by selecting a nosepoke hole representing a given asset, after which the lights are immediately extinguished for 2 sec. Subsequently, the selected hole and the two adjacent holes to the left and right are again illuminated, but no longer blinking. Rats nosepoke a second time into one of the illuminated holes to indicate a buy, hold, or sell option. One of two tones immediately indicates whether their choice resulted in a gain or loss, and rats are free to collect the reward. The volume of reward a rat receives on a given trial is proportional to the amount gained or lost, added to some reference point (e.g. when selling at a loss, $Volume_n = Price_n - Price_{n-1} + 0.15$ ml). Rats also have the option of 'holding' on any given trial, which results in a dividend payment added to the reference volume. The dividend amount is based on the individual subject's current holdings of that stock, and has a 2/3 probability of being low (e.g. 2% of holdings) and a 1/3 probability of being high (e.g. 6% of holdings).

Results: On average, rats (N=24) chose the riskless hold option on over half of trials despite earning 50% less per trial-second than buy and sell options. However, on trials preceded by a loss rats chose more equally among the 3 options and earned significantly more. Rats consistently chose the buy option when asset prices were higher, to sell when prices were lower, and to hold when prices fell in between.

Conclusions: These results suggest that rats, like humans, are susceptible to suboptimal market behavior. The current paradigm constitutes an initial step toward modeling financial markets in rats.

Feedback-based learning in aging: Specific contributions of striatal and hippocampal systems

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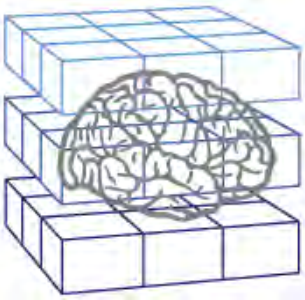
Objective: A substantial literature implicates the striatum in learning from immediate feedback – particularly in coding reward prediction errors (RPEs). More recent studies, however, suggest that the hippocampus plays a similar role in learning from *delayed* feedback. Both of these brain regions show evidence of structural and functional decline in normal aging, but behavioral research strongly suggests greater decline in hippocampal versus striatal functions. This study tests the hypothesis that age differences in feedback-based learning increase with feedback delays and reliance on the hippocampus.

Methods: Younger and older adults were scanned using fMRI during a learning task with choice feedback presented immediately or after a brief delay. Participants then completed a surprise memory test for trial-unique feedback stimuli and made economic decisions about choice stimuli for a cash bonus. FMRI analyses examined parametric effects of RPEs and subsequent memory ratings for outcome stimuli, and whether these effects depended on age and feedback-delay condition. Finally, we determined if RPE signals in these memory regions differentially predicted younger and older adults' subsequent economic decisions about cues from the learning task.

Results: Younger and older adults had similar learning behavior in both conditions, but showed different neural response to prediction errors. While younger adults exhibited the expected shift in PE response from the striatum to the hippocampus with feedback delays, older adults showed relatively reduced hippocampal PE and increased striatal PE with feedback delays. Feedback delays also resulted in better episodic encoding for outcomes across both groups, but this effect was related to increased hippocampal activity only in younger adults. In addition, RPE signal predicted post-learning economic choice performance for cues in the delayed condition, but this relationship differed by age and brain region. Positive correlations were observed in the striatum for young adults and in the hippocampus for older adults.

Conclusions: Feedback timing has a similar effect on learning behavior and memory for outcomes across adulthood, but the neural mechanisms of these effects change with age. Age is associated with a shift toward greater striatal involvement, and diminished hippocampal involvement, in learning from delayed feedback. These findings suggest that the hippocampus plays an important role in value learning across adulthood, and the striatum can compensate for functional decline in the hippocampus to support memory-dependent decision making.

Acknowledgements:
This research was supported by the National Institute of Aging grant R24-AG039350 subaward to N.R. Lighthall and grant R01-AG019731 to R. Cabeza.



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Poster Session III
By Poster Number

Reach trajectories as another index of preferences in dietary choice

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Objective: Whereas classic decision making paradigms focus on outputs of the decision process (i.e., choices and response times), there has been increasing interest in measuring the decision process as it unfolds using mouse-tracking. Recently, Sullivan et al. (2014) used this method to index the relative influence of tastiness and healthiness on food choice, finding that tastiness influences the choice trajectory earlier than healthiness. Here we aim to replicate and extend these findings using a different measure of movement trajectories, collected with a robotic manipulandum. In particular we are interested in testing whether the earlier influence of taste is invariant to task demands (suggesting that taste prioritization is a "bottom-up" limitation) or whether this result is specific to settings where attention must be split between taste and health (suggesting that prioritization occurs via "top-down" mechanisms).

Methods: Experiment 1 was adapted from Sullivan et al (2014). Participants (N=30) made hypothetical choices between food pairs by making a reaching movement to their preferred food using a robotic manipulandum (KINARM). Food images were displayed on the left vs. right side of the screen from the initiation of movement until an item was selected by stopping on its image. Prior to this task, participants rated each item for both healthiness and tastiness. Participants in Experiments 2-3 (N=21 each) performed this same task for a block of trials, followed (Exp 2) or preceded (Exp 3) by blocks of trials in which the participant was instructed to focus only on one attribute (e.g. choose healthier).

Results: In Experiment 1 we replicate the finding of an earlier influence of taste than health on the decision process when freely choosing how much to attend each attribute. However, when attending to one attribute (Exp 2-3), the influence of health was not delayed relative to taste: the influence of taste on 'choose tastier' decisions did not onset earlier than the influence of health on 'choose healthier' decisions, suggesting that these can both be processed similarly early.

Conclusions: We show that robotic manipulanda can be used as an alternative to mouse-tracking to measure the value-based choice process. Specifically, we replicate a previously reported prioritization of taste over health attributes in influencing movement trajectories. In separate experiments we show that this is not related to the time required to process one attribute or another, but is instead more likely related to attentional prioritization of tastiness. Future work will build on these findings by using force fields to manipulate in addition to measuring movements kinematics.

Acknowledgments: This study was funded by the John Templeton Foundation, the Princeton Neuroscience Institute Innovation Fund (PAB), and the C.V. Starr Foundation (AS).

Reference: Sullivan, N., Hutcherson, C., Harris, A., & Rangel, A. (2015). Dietary Self-Control Is Related to the Speed With Which Attributes of Healthfulness and Tastiness Are Processed. *Psychological Science*, *26*(2), 122–134.

Neural systems responding to degrees of social and non-social uncertainty as well as fairness

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Objective

Recently, two main theories have been proposed to explain how the brain might encode social and non-social motivational decision making: the extended common currency and the social valuation specific schema (Ruff 2014). One way to test these theories is to directly compare neural activity related to social and non-social decision outcomes within the same experiment. The present fMRI study was set up to compare neural activity reflecting reward and risk prediction errors (RePE and RiPE) during social and non-social gambling tasks. We formed two sets of hypotheses. We hypothesised that during outcome anticipation similar brain regions would represent RePE and RiPE using similar response profiles in the social and non-social domain. Second, based on a recent model of anterior insula (Singer 2009), we hypothesised that at outcome delivery clusters reflecting non-social RiPE would also reflect fairness of outcomes and uncertainty but not monetary utility in the social domain.

Methods

We used a trust betting game to vary uncertainty along a social dimension (trustworthiness). Concurrently we used a card game (Preuschoff 2006) to vary uncertainty along a non-social dimension (pure risk). The trust game was designed to maintain the same structure of the card game. In the card game participants placed a bet on whether the second of two sequentially presented cards would be higher or lower than the first. Presentation of the first card generated a RePE and RiPE. In the trust game participants bet on whether an unknown trustee would act trustworthily. Revealing the face of the trustee then allowed the participant to make subjective estimates of the likelihood of potential wins or losses. Thus, changes in perceived trustworthiness generated a RePE and RiPE once the trustee face was revealed. At outcome revelation a second RePE and RiPE was generated in both games.

Results and conclusions

Parametric and connectivity analyses (20 participants) revealed that processing of social and non-social forms of uncertainty relies on largely similar networks. Importantly, we found that during outcome anticipation activity in subcortical regions (e.g. ventral striatum) reflected RePE in both social and non-social domains. In contrast, activity in cortical regions (e.g. anterior insula and dorsal ACC) reflected RiPE in the non-social domain and RePE in the social domain.
At outcome delivery, in the non-social domain activity in a network of regions including anterior insula, dorsal ACC and OFC reflected RiPE. Crucially, we found that these same regions were modulated by both fairness and uncertainty of social outcomes, but not by actual gains and losses. On one hand these results speak in favour of the extended common neural currency schema showing that the same brain regions process social and non-social uncertainty. On the other hand, this study provides also evidence of distinct neural processes involved in resolving uncertainty when fairness and social rewards are at stake.

References

Preuschoff, K. et al. (2006). *Neuron*, 51, 381-390.
Singer, T. et al. (2009). *TICS*, 13, 334–40.
Ruff, C. et al. (2014). *Nature Reviews Neuroscience*, 15, 549–562.

Neural Mechanisms Supporting Persistent Maladaptive Food Choices

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Objective: People routinely make poor choices, to the detriment of their health and well-being. Yet, despite knowledge of the negative consequences, maladaptive choices persist. Such behavior is particularly common in choices about which foods to eat, but the neural mechanisms that support persistently poor food choices and how they relate to everyday behavior are unknown. We examined these issues in individuals with Anorexia Nervosa (AN), whose persistent choice of low calorie foods poses a serious and sometimes fatal threat.

Methods: We used functional magnetic resonance imaging (fMRI) to examine brain activity while 21 individuals with AN and 21 healthy controls made decisions about which foods to eat. Participants with AN were receiving treatment aimed at weight restoration to a medically healthy weight, and were tested within 24 of hours of hospitalization. The task comprised three phases. In the first two phases, participants rated the healthiness and the tastiness of high- and low-fat food items. Next, in the third phase, each participant was asked to make a series of choices between a reference item, randomly selected among items rated by the individual as neutral in both the health and taste rating phases, and each of the other foods. Participants were informed that, immediately following the task, they would be served one of their choices as a snack and were expected to consume it—creating a real-world contingency for their choices. This paradigm allowed an individual's ratings of food to determine the reference item, which was critical in comparing behavior of healthy controls with individuals with AN, as the two groups were expected to rate the health and tastiness values of food differently. To determine whether choice responses in the task were related to actual eating behavior, we compared responses on the food choice task with caloric intake in a lunch-time meal the next day in which participants were presented with a buffet-style array of foods and asked to eat whatever they wished. Food was weighed before and after and amount consumed in grams and kcal was calculated.

Results: Behaviorally, choices on the experimental food task correlated with the amount of food consumed in a meal the next day. Using fMRI, we found that the dorsal striatum was more strongly associated with food choices in AN relative to controls, whereas ventral striatal activity did not differ between groups. Moreover, fronto-striatal connectivity during the experiment predicted the amount of food consumed in a meal the next day.

Conclusions: These findings demonstrate that activity in fronto-striatal brain circuits is related to the persistent restrictive intake seen in AN, and may relate to persistent maladaptive behavior more broadly.

Acknowledgements:
This study was funded by the Global Foundation for Eating Disorders and the NIMH (#R01 MH079397, K23 MH076195).

Ventral tegmental dopaminergic stimulation causes preference reversals

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In natural environments, animals make foraging decisions based on the values of potential food sources, foraging more at locations associated with high values. To accomplish this, animals must first learn the values of available options. The dopaminergic reward prediction error (RPE) hypothesis is the dominant view of how biological reinforcement learning works, proposing that midbrain dopamine neurons encode the difference between actual and predicted rewards. Under this theory, dopaminergic RPEs serve as a teaching signal, with dopamine bursts signaling better-than-expected outcomes that increase the subjective value of associated options. There is an enormous amount of correlational support for this hypothesis, but few studies assess the causal role of dopamine in reinforcement learning. Here, we examine how selective microstimulation of midbrain dopamine neurons impacts reinforcement learning. We trained two rhesus macaques on the matching law foraging task in which two options yielded water rewards with equal probability (25%) but different magnitudes. The reward magnitudes changed abruptly over time, requiring constant updating of subjective value estimates. In select blocks, we stimulated dopaminergic neurons in the ventral tegmental area along with the delivery of the smaller magnitude reward; this stimulation resulted in a preference reversal by which monkeys chose the smaller (but stimulated) option. Consistent with a dopaminergic mechanism, administration of the dopamine D2 receptor antagonist raclopride reduced the size of this effect. Aspects of trial-by-trial choice dynamics following both reward and combined reward-stimulation were captured by standard reinforcement learning models. These results provide causal evidence that midbrain dopamine neurons carry a teaching signal that updates value estimates that guide value-based decision-making.

Wired For Now? Orbitofrontal Cortex-Ventral Striatum Structural Connectivity Predicts Individual Differences in Delay Discounting

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Objective: When reward magnitude and temporal distance are placed in tension, the rate at which people discount future rewards, *k*, varies across individuals. fMRI research has implicated several neural regions in this delay discounting phenomenon, but anatomical connectivity among these regions is unclear. Previous studies have found a correlation between individual differences in delay discounting and white matter connectivity microstructure, but regions implicated are very broad; results do little to tie specific anatomy to specific function. Given that the task involves comparing immediate and future financial rewards, here we examine individual differences in white matter connectivity between the ventral striatum (vSTR), thought to be involved with valuation, and the orbitofrontal cortex (OFC), often implicated in prospection and mental simulation.

Methods: Thirty-three adult participants completed the study. Each participant completed a behavioral delay discounting task, in which they were given series of forced choices between an immediate reward and a reward at varying points in the future. Behavioral data were used to calculate their discounting slope, *k*. As a control, participants also completed a go/no-go motor inhibition task. In addition to behavioral testing, subjects were scanned using 64-direction, high-resolution diffusion tensor imaging (DTI) that provides information about structural white matter neural connectivity. DTI data were analyzed using the FSL probabilistic tractography pipeline using the ventral striatum as a starting seed region and the OFC and its subregions as the target brain regions. As a control seed, we used the dorsal striatum. We then used multiple regression analysis, controlling for age and gender, to see if streamlines (white matter connectivity) between these regions were predictive of delay discounting performance.

Results: White matter connectivity between the vSTR and OFC significantly predicted individual differences in delay discounting *k*, i.e. financial impulsivity. Microstructure connectivity between these regions did not predict performance on the control task, go/no-go. Similarly, streamlines from the control seed of dorsal striatum to the OFC predicted neither delay discounting nor go/no-go scores. More specifically, ventral striatum connectivity to the superior and middle orbitofrontal cortices significantly predicted delay discounting, while medial orbital and inferior orbital cortices did not significantly predict discounting behavior, after controlling for multiple comparisons.

Conclusions: Individual differences in how we are "wired" predict our ability to delay gratification for future monetary rewards. Our results suggest that variation in structural connectivity between neural regions associated with valuation and mental simulation account for individual differences in financial impulsivity.

Acknowledgements:
This study was funded by the NIH, grant # RO1MH091113.

Fos expression after exposure to an effort discounting procedure

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Objective: Apathy is a hallmark of numerous psychiatric disorders, and unwillingness to initiate or maintain an effortful change in habitual behavior is thought to impede the development of more healthful behavior patterns. However, our understanding of the processes regulating instances of effort-aversion is incomplete. This project addressed this research gap by measuring markers of neuronal activity to determine the contribution of different brain areas to the decision to work for a food reward.

Methods: 64 Long-Evans rats (N=32 per sex) participated. Rats were divided into three groups: a food-restricted experimental group; a food-restricted control group; and an unrestricted food control group. Rats in the food-restricted experimental group were trained on an effort-discounting task based upon a modified adjusting amount procedure (Richards et al. 1997, J Exp Anal Behav 67: 353). In this procedure, rats chose between 150-µL of sucrose solution available following completion of an effortful response, and a smaller sucrose reward available following a negligible-effort response. Rats were tested on five effort levels (0.01, 0.15, 0.35, 0.6, 0.9 Ns), varied daily, where the effort was determined from the force integrated over time. Food-restricted and unrestricted control rats were placed in the operant chambers but did not complete the task. Behavioral data were used to characterize individual differences in the willingness to engage in effortful responding by constructing effort discounting curves and calculating the area under the curve. Prior to being euthanized on their last session, rats experienced 5-10 sessions at the 0.6 Ns effort condition. Brain tissue was then stained for cFos, a habituating marker of neural activation, and ΔFosB, a member of the Fos family of transcription factors that accumulates. Numbers of Fos-positive cells were counted visually, and compared between groups for each region.

Results: For the trained rats, the subjective value of the 150-µL reward decreased hyperbolically as a function of increasing effort. When rats were tested at a single effort prior to their last session, the subjective value of the 150-µL sucrose was stable across sessions. Preliminary cell-counting suggests an enrichment of cFos-positive cells in dorsal striatum, and FosB-positive cells in accumbens, for food-restricted, experimental animals over controls.

Conclusions: These results are consistent with the view that the striatum is involved with the choice to perform effort for a food reward, rather than the value of the reinforce itself.

Acknowledgements:
This study was funded by the NIH, grant # T32 DA007262. Many thanks to Karen Bard, Elizabeth Growden, and Veida Lekakh for their help conducting these experiments, and to Vanessa Wilson for her assistance with analysis.

Predicting real life stock purchase via individual differences in demographics, personality, risk preferences, and neural processing

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Objective: Previous studies have shown the influence of personality, education, cognitive abilities, or age on financial life choices. Our aim is to combine the separate data sources, namely demographics, personality, behavior, and fMRI, in order to build a comprehensive model aimed at predicting real life stock purchase. An additional aim is to show that including brain activation values as measured in the ventral striatum (VS) and the anterior insula (AI) is critical to significantly improving such a model.

Methods: Data of 113 adult male subjects (38.72 ± 6.70 years) who participated in an ongoing study have been analyzed. Each subject underwent a series of three previously established paradigms investigating risk preferences and the ability to assess a stock correctly (stock assessment error). In addition, results from the Intelligence Structure Test 2000R as well as two personality tests together with a financial knowledge questionnaire were collected. The personality and behavioral data were used in a principle component analysis (PCA) to extract robust factors and reduce measurement error. Brain activation values were extracted from the mentioned regions of interest (ROI). Subsequent analyses used logistic regression models in order to build three separate models. The best model was then assessed via receiver operating characteristic (ROC) curves and likelihood ratio (LR) tests.

Results: The first logistic regression model only included demographic data, while the second model further included behavioral and personality measurements. Additionally, the third model integrated brain activation values and was found to be the significantly best model by explaining most of the variance of buying stocks in real life (pseudo $r^2 = 0.6116$). This most comprehensive model shows that specifically decreased AI and increased VS activation at certain time points of a stock exchange game can explain approximately 15% of the variance. Furthermore, ROC analysis revealed that this model is excellent (ROC area = 0.9569) at separating individuals who purchase stocks from those who do not.

Conclusions: The results of this study depict a comprehensive model predicting stock purchase via demographic, personality, behavioral, and brain activation data. While an exclusion of the fMRI data makes it still possible to build a significant model, our results emphasize the importance of including fMRI brain activation values in the analysis of real life financial decisions.

Acknowledgements: This study was partly funded by the Frankfurt Institute of Risk Management and Regulation.

Age Differences in Discounting of Time, Probability, and Effort Across Monetary, Social, and Health Domains

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Objective: Some have suggested that a unitary value system in the brain might lead to high consistency of preferences across different types of discounting across domain and that this may systematically change with age. To investigate this we examined adult age differences in temporal, physical effort, and probability discounting across monetary, social, and health domains.

Methods: Fifty-nine healthy participants aged 22–81 (mean 45.63, SD=17.12, 63% female) completed hypothetical discounting tasks, which included three types of costs (time delays, probability, effort requirements) across three domains (monetary, social, health). Participants made choices between a smaller magnitude reward with a shorter time delay / higher probability / lower level of physical effort required and a larger magnitude reward with a longer time delay / lower probability / higher level of physical effort required. Within each of the tasks, we computed the percentage of choices in which each participant selected the lower cost reward (associated with shorter time delays, higher probability, or lower effort). Finally, we investigated age related correlations with each variable.

Results: Correlations revealed that with increasing age, subjects were less tolerant of time delays (higher discount rates) in the health ($r = –.31$, $p < .02$) and social ($r = –.41$, $p < .001$) domains but there was no age difference in the monetary domain ($r = –.16$, $p < .22$). Older adults were more tolerant of effort costs (lower discount rates) in the monetary domain ($r = .31$, $p < .02$) but there were no age differences in the health ($r = .14$, $p < .29$) and social ($r = .19$, $p < .15$). domains. Older adults were less tolerant of lower probabilities (higher discount rates) in the social domain ($r = –.31$, $p < .02$) with a trend in this direction for the health domain ($r = –.22$, $p < .09$) but there was no age difference in the monetary domain ($r = –.11$, $p < .40$).

Conclusions: We found evidence for increases with age in the discounting of temporal delays and lower probabilities in the social and health domains. Older compared to younger individuals were less likely to choose options that involved longer time delays (months) or lower probabilities (<100%) of experiencing the social interaction or receiving the health benefit. The findings suggest that older adults may be more motivated to obtain social rewards immediately and with certainty. This pattern was not observed in tolerance of physical effort. Finally, in contrast to prior studies we did not find age differences in temporal discounting of monetary rewards.

Acknowledgements:
This research was supported by National Institute on Aging Pathway to Independence Award R00-AG042596 and National Institute on Aging grant R01-AG044838.

Character count: 2184

Model-based learning predicts increased patience in intertemporal choice

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Objective: Many of life's most important decisions can be viewed as choices between smaller, sooner rewards and larger, later rewards. In the context of such intertemporal choices, the ability to forgo immediate gratification in order to maximize long-term reward varies greatly from person to person. In the lab, this trait is quantified as the rate at which subjective utility is discounted as a function of time ('discount rate'). Recent work suggests that individuals who tend to prospectively recruit richer representations of future outcomes may discount future rewards less steeply (e.g., Peters & Büchel, 2010; Benoit et al., 2011). However, the mechanisms by which prospection fosters greater patience are not well understood. Reinforcement learning (RL) makes the distinction between two evaluative systems: a 'model-based' system which evaluates an action by simulating possible future outcomes, and a 'model free' system that retrospectively assigns value to actions according to prior experience. It is possible that simulating future outcomes during intertemporal choice relies on the same neuro-cognitive mechanisms as simulating future paths during model-based reinforcement learning (Doll et al., 2015). As a first step toward investigating this overlap, here we ask whether individual differences in temporal discounting are related to the relative recruitment of model-based and model-free learning systems.

Methods: Participants performed a temporal discounting task, in which they made choices between smaller, immediate rewards and larger later rewards, followed by a sequential RL task designed to dissociate model-free and model-based choice behavior (Daw, 2011). We used a hyperbolic model to estimate participants' discount rates, a measure of their relative patience. From the sequential RL task, we derived indices reflecting the extent to which each participant's behavior reflected signatures of model-based and model-free choice. We then compared estimated discount rates to these indices of model-free and model-based choice (Daw, 2011).

Results: Within-subjects analyses revealed that 'model-based' choice was correlated with greater patience (low discount rate) in the TD task.

Conclusions: These results suggest that there is a common mechanism underlying prospective, model-based choice during reinforcement learning and more patient intertemporal choices. Moreover, these findings highlight the interdependence of learning and decision processes, demonstrating how differences in evaluative learning shape idiosyncratic choice.

Acknowledgements:
This work was supported by NIH Grant R03DA038701, the Dewitt Wallace Readers Digest Fund, and a generous gift from the Mortimer D. Sackler MD family.

Value aftereffects: evidence for dynamic adaptation in the valuation process of human subjects

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Objective: We attempt to systematically bias bidding behavior with a value-based adaptation manipulation, mimicking the effects of classical sensory adaptation paradigms. We hypothesize that the subjective values of goods – as reflected by dollar value auction bids – can be increased or decreased after prolonged exposure of the subject to specific valuation trajectories.

Methods: The experimental protocol consisted of a behavioral auction experiment employing two adaptation blocks interspersed between three test auction blocks. Forty-four adults (24 female), from 18 to 45 years old ($\mu = 23.43$ years) participated. During bidding blocks, subjects were asked to declare a willingness-to-pay (WTP) for snack items. The bids were elicited via an incentive-compatible Becker, Degroot & Marschak auction. During adaptation blocks, subjects were asked to evaluate repeatedly (300 trials per block) the pleasantness of either high or low-value snack items (as determined by ranks obtained from the initial bidding block).

Results: Subjects show a systematic and transient shift in their average bids during the auction blocks, as predicted by relative value coding. That is, bids following a history of high-value adaption are lower in magnitude than bids following low-value adaptation. The bids themselves exhibit a regression toward the mean from the very first block as trials elapse. A linear regression of bid deviations on past bid values reveals a significant positive effect of the last immediate bid. In contrast, there is a significant negative effect of a longer-running aggregate of past values. These relationships also appear to vary over time, with the negative effect of a long-running average being strongest at the beginning of bidding blocks, and vice versa for the effect of immediately past bids.

Conclusions: These findings suggest that the subjective valuation of goods is dynamically affected by the recent history of experiences, and that temporal adaptation may be a general phenomenon across both sensory and valuation domains.

Neural Representation of Value of Information

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Introduction: In many types of decisions, an agent acquires some pieces of information over time, e.g. reading abstracts to select which posters to visit. Information is often associated with cost (e.g. reading time), and the agent decides whether to acquire information by comparing its value against its cost. Because information has no intrinsic value, its value only comes from the agent's ability to make a decision more adaptively in the future. According to decision theory, normative value of information is expected marginal gain from making an informed decision, and requires simulation of the self's choice and its expected utility under all possible contents of information. Although proper valuation of such pure information is fundamental to a variety of decision problems, we still know little about its neural basis. We conducted a behavioral study to examine the extent to which value of information conforms to normative predictions, and an fMRI study to investigate neural representation of value of information.

Methods: The experiments involved a series of gambles. Each gamble was consisted of two possible monetary outcomes, one gain and one loss, and their probability was (50%, 50%). Subjects chose whether to play each gamble. Next, we presented an additional piece of information for each gamble. When purchased, the information provided more precise prediction of outcomes by updating probability distribution, based on which subjects could choose whether to play the gamble. For example, the information could reveal that probability over outcomes was either (33%, 67%) or (67%, 33%), instead of (50%, 50%). We displayed potential probability distributions by the orientation of a partition line overlaid on a roulette wheel, and asked subjects to choose whether to buy the information at some monetary cost.

Results & Discussion: Behaviorally elicited value of information was largely consistent with normative predictions; value of information was larger when more precise prediction were supplied, and when potential outcomes were larger. Critically, when the information would not change probability, most subjects reported it as valueless. From fMRI, we found that activation in medial prefrontal cortex and striatum was correlated with value of information. We also found a number of regions which activation was correlated with expected value of gambles. Critically, these two types of representation were overlapped in medial prefrontal cortex. These results suggest that value of information, which depends on simulation of own choice, shares some neurocognitive processes with other types of valuation, consistent with the "common currency" hypothesis.

Gaze data reveal different choice processes underlying model-based and model-free reinforcement learning

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Objective: When making decisions in multi-stage environments, some people behave as if they are 'model-free', simply repeating reinforced actions, while others behave as if they are 'model-based', taking into account whether the previous outcomes were likely or unlikely given their choices. Research in this domain implicitly assumes that both types make decisions at the same time, using a similar process, but that model-based learners consider where choices may lead them. We sought to test these assumptions by examining the choice process during a learning task using eye tracking. Specifically, we tested (1) whether model-free and model-based subjects engage in the same value comparison process, and (2) whether model-free subjects ignore task-relevant information or simply misinterpret that information.

Methods: We carried out an eye-tracking experiment using a well-known two-stage learning task (Daw et al., 2011) that discriminates between model-based and model-free learning. 43 subjects completed 300 trials of the experiment that consisted of two conditions with 150 trials each. In the first condition, we replicated the standard design used in the literature, where subjects first choose between two options. Each of these options probabilistically leads to one of two different second-stage decision screens. Each second-stage screen has two options that probabilistically yield fixed rewards, and these probabilities slowly vary across trials. In the second condition, we randomly varied the transition probabilities from trial to trial and provided subjects with on-screen visual cues indicating these deviations.

Results: Using a standard computational model, we classified subjects into model-based and model-free learners. In the first condition, we found that model-based learners seemed to know ahead of time what they would choose, while model-free learners exhibited a back-and-forth comparison process. The model-based learners were more likely to look at the best option first, were most likely to look at only one option, and were relatively unaffected by gaze time. In the second condition, the model-free learners mostly ignored the visual cues providing information about transition probabilities.

Conclusions: Our results revealed that model-based learners seem to know what they will choose before the options even appear, while model-free learners undergo a value comparison process that mostly ignores the structure of the environment. This suggests that the differences between model-free and model-based learners are deeper than has been previously suspected, which could have major implications for the neuroscience results based on these tasks.

Dopaminergic genes predict the cost of cognitive control and reliance on habit

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Objective: Human decision makers attach an intrinsic cost to the exertion of mental effort. Recent research has revealed an important role for prefrontal neural structures in the registration of these costs, but little is known about the role for neuromodulation in this process. Following animal research focusing on physical effort, we tested the hypothesis that dopamine plays a role in cognitive effort discounting. A secondary goal was to evaluate the role of dopamine and effort costs in the balance between habitual and goal-directed action selection.

Methods: Ninety-seven participants supplied a saliva sample for genotyping analysis (striatal: DARPP-32 C957T, rs1076560, DAT1; prefrontal: COMT, C-521T), and performed two tasks. In the first, we measured sensitivity to cognitive costs by having participants freely choose between activities with different cognitive demands. Participants also completed a sequential two-step task that dissociates between habitual and goal-directed choice. Analyses focused on differences in cognitive costs and habitual choice as a function of genetic variations related to dopaminergic function in the striatum and prefrontal cortex.

Results: First, choice behavior revealed the standard preference for tasks with lower demands for mental effort. Second, we found that a variation in a gene coding for the dopamine D2 receptor (C957T) was related to the size of this bias, with increased expression related to decreased demand avoidance. Next, we computed two composite scores separately for the polymorphisms related to dopaminergic functioning in striatum and prefrontal cortex, and found that increased dopaminergic functioning in the striatum was positively related to effort avoidance, but enhanced functioning in the prefrontal cortex was negatively related to effort avoidance. Third, hierarchical logistic regressions revealed that cognitive costs were predictive to habitual action selection, but this relationship was modulated by striatal genotypes. Cognitive costs were predictive of habitual choice only for people with reduced dopaminergic functioning.

Conclusions: Our results suggest a role for striatal and prefrontal dopamine in the discounting of mental effort costs, analogous to its role in physical effort-based cost/benefit analyses. They also show that cognitive demand avoidance plays a role in the regulation between habitual and goal-directed decision making. We speculate that these results may have implications for understanding clinical conditions such as attention deficit disorder and Parkinson's disease, where both mental effort allocation and dopaminergic function have been implicated.

Acknowledgements: This research was supported by National Institute of Mental Health Grant MH062196 and a grant from the John Templeton Foundation.

The neural substrate of maternal love in shopping: comparing general linear model and searchlight mapping

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Acknowledgements: This study was financially sponsored by the Ministry Of Science and Technology in Taiwan (MOST-103-2410-H-006-030 for CCK, MOST-103-2922-I006-198 for MHW) and the Top-Notch University Grant to NCKU (D104-36A06). The authors like to thank the consultation and support provided by NCKU MRI center. Special thanks go to Dr. Jinming Chen in China Medical University Hospital (CMUH) for his assisting fMRI experiments there.

Abstract

Paternal love plays vital roles in family and social functions. While the studies on parental love have shown that when seeing/hearing children of their own, parents show higher BOLD responses in reward-related brain areas (such as periaqueductal grey, or PAG), how parents' shopping behaviors are affected, especially if they buy more for their children at the cost of buying less for themselves, remain to be elucidated. The current 3T fMRI study recruited and observed 21 first-time mothers' brain activities when they undertook a virtual shopping task, where 100 mother-related (perfumes, purses, and clothes) and 100 children-related (toys, books and gender-appropriate clothes) items (with prices underneath) were presented in a slow event-related fashion (TR=2s, 16s per trial). Behaviorally, mothers did buy relatively more for their child than for themselves. Neuronally, general linear model (GLM) revealed largely similar brain circuits for both "MotherItems-Buy (or MB) vs. MotherItems-NotBuy (MNB)" and "ChildrenItems-Buy (CB) vs. ChildrenItems-NotBuy (CNB)" contrasts, including middle frontal, hippocampal, and subcortical areas; and voxelwise correlation of "CB vs. MB" contrast against each mother's relative children/self buying ratio further revealed both positively and negatively correlated regions intermingled in insula, suggesting the interplay between subjective reward and increasing economic costs. Additionally, multivariate searchlight analyses on "CB vs. CNB" trials revealed subjective reward-related areas, including ventromedial prefrontal, ventral striatum, PAG, dorsal anterior and posterior cingulate regions; whereas the "MB vs. MNB" searchlight revealed partly overlapping (with "CB vs. CNB", such as PAG) but largely separate regions (such as right caudate, insula, and bilateral superior temporal gyrus). Additional upsampling and downsampling (correction for imbalanced "X-Buy vs. X-NotBuy" trials), different classification kernels (GNB, LDA, and SVM), and the two searchlight radius (1 or 2 voxels) sensitivity measures, all showed the similar pattern. Taken together, these results further extend the power of maternal love by showing the strong engagement of subjective reward-related brain areas in the family shopping for, in addition to viewing/hearing, one's own child, and also help illustrate the complementary advantages provided by different fMRI analysis methods.

Divisive Normalization Yields Attraction and Compromise Effects

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Objective: There is growing evidence that choice behaviour depends systematically on the choice set in a manner which violates a necessary condition for a rational choice model. For instance, adding an alternative to a choice set which is dominated in some attribute dimension can lead to an absolute increase in the choice probability of an existing alternative (e.g. the *attraction* effect; Huber et al., 1982; Tversky & Simonson, 1993; Rieskamp et al., 2006). A similar result can be demonstrated with the introduction of an alternative which is similar, but not dominated (the *compromise effect;* Simonson, 1989).

Here, we propose a neurobiologically-based model of such attribute-level choice phenomena. The model relies on a relative comparison of attributes by means of *divisive normalization,* a neural computation with features widely observed in cortex across many sensory modalities and many species (Carandini & Heeger, 2012). Divisive normalization scales (or normalizes) neural activity to the aggregate input to a neural circuit, and efficiently codes sensory information consistent with the Efficient Coding hypothesis (Barlow, 1961).

Results: Introducing attribute-level normalization into a neuroeconomic choice model simultaneously yields both the attraction and compromise effect. The statement of these results are presented in two formal theorems, and characterize the choice sets for which the result will hold. Intriguingly, attribute-level normalization also yields preferences that are convex in attributes.

Conclusions: These results suggest that choice effects which arise from an ordering of attributes can result from known cortical computations. Since the divisive normalization computation is grounded in the efficient coding of information, this suggests that attribute-level choice "irrationalities" may be optimal given neurobiological constraints.

Visual spatial frequencies affect value-based choices

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Background and Objective: Recent studies showed how visual saliency and decision processes interact (Towal et al., 2013) and how different aspects of low-level visual properties propagate to influence the final decision humans make (Milosavljevic et al., 2011). It has been shown that low spatial frequencies (LSF) describe elements that cover large areas of an image and drives global perception (the gist) while high spatial frequencies (HSF) describe the details of a scene. This visual processing follows a predominately "coarse-to-fine" strategy. First, LSF features are processed and only then are HSF features processed. LSFs reach higher-order (value related) processing areas first (vmPFC) and are then fed back into earlier visual areas to interact and guide further processing of HSF information. This raises the possibility that spatial frequencies' processing and top-down modulations of visual input interact with value-based choices. We explored whether spatial frequency information of different product pictures would influence subject's choices.

Methods: Each picture underwent low and high pass filtering. We used four levels of frequencies (16, 32, 64, 128 Hz), two levels of filter type (high vs. low pass), and two levels of exposure time (50ms/150ms). In the *perceptual* task, subjects observed a filtered image of a product and had to decide whether they recognize the image. Thereafter, they had to pick which text description matches the image they just saw. We extracted for each subject a spatial frequency sensitivity score that represented the influence of exposure time, filter type, and frequency on subject's classification performance.

A day later, we used an auction procedure designed to elicit subjects' true valuations (Becker–DeGroot–Marschak auction). Subjects viewed a single product and reported their maximum willingness to pay. In subsequent choice trials, subjects had to decide which product they prefer – the filtered product on the screen or an unfiltered reference product.

Results: We found that for short presentation time (50ms) when the value of the filtered product was higher, subjects tend to choose it *more* in the LSF condition compared to the HSF condition. We also found a correlation between subjects' sensitivity scores measured in the perceptual task and the propensity to choose the filtered option in the choice task.

Conclusions: We demonstrate that presenting products in different spatial frequencies affects subjects' choices suggesting a strong interaction between visual coarse/fine features and choice. The correlation we found raises the possibility that sensory sensitivity might serve as a basis for consumers' segmentation.

Investigating the role of *SHANK3* in social decision-making in free-ranging rhesus macaques

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Autism spectrum disorders (ASD) are characterized by abnormalities in social evaluative and decision-making that arise from the interaction of genes and experience during development. Mutations in the SHANK3 gene have been identified as one of several monogenic causes of ASD. The functional role of SHANK3 in neural development and function has been illuminated by studies in transgenic mice and flies. However, the role of SHANK3 in the social decision-making aspects of ASD has proven more difficult to decipher, in part due to the relative simplicity of mouse and fly social behavior and the relatively impoverished nature of laboratory social environments. An alternative approach is to study naturally occurring genetic variation in free-ranging populations of animals with complex, human-like social behaviors and environments. Rhesus macaques provide a candidate model species due to their extensive use in both laboratory and field research, homologous neural circuitry, complex social behaviour, and large hierarchically organized social groups. Like humans, rhesus macaques constantly face social decisions regarding whom to affiliate with, support in disagreements, whom to challenge, and whom to defer to. Here, we identify SHANK3 sequence variants in a large free-ranging population of rhesus macaques on Cayo Santiago island and the patterns of social choices they predict.

We sequenced the SHANK3 region in an initial sample of 285 rhesus macaques. We identified one C>T single non-synonymous nucleotide variant (SNV), with the major allele coding for Proline (CCT) and the minor allele coding for Leucine (CTT). Forty animals were heterozygous at this allele. We investigated the impact of this SNV on social phenotypes using social network analysis, which describes each animal's affiliative decisions in terms of both the quantity and quality of their own social connections and the social connections of those they affiliate with. These analyses were based on 2 years of observational data regarding the types and frequencies of interactions occurring between animals in this population. We found that animals heterozygous at this locus had stronger affiliative "betweenness", which is a social metric quantifying an animal's tendency to affiliate with groups of animals that do not affiliate with each other and thus connect otherwise separate social clusters. We speculate that this SHANK3 SNV may increase social 'adventurousness', thereby increasing willingness to interact with partners outside of one's preexisting social circles. Further functional study may provide additional insight for functional significance of this SNV.

Linking differences in baseline physiology to self-control performance

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Objective: The ability to self-regulate has been associated with a wide range of positive life outcomes, from higher socio-economic status to better mental and physical health. Less clear is the path through which self-control is associated with physiological markers of health. We use heart rate variability (HRV) measures to link differences in baseline physiology to self-control performance in a food choice task.

Methods: After 49 healthy men had rated food stimuli for health and taste aspects, we recorded their baseline ECG during 3 minutes at rest. They then made a series of choices between two food items, one of which was always healthier than the other. Self-control success was measured as the proportion of trials in which the participant overruled his taste preferences and chose the healthier, but less tasty food if the two attributes were in conflict.

Results: Total HRV (measured as standard deviation over all RR intervals, SDNN) correlated positively with the frequency of successful self-control use in the food choice task ($r = 0.39$, $p = 0.006$). Moreover, higher HRV was associated with increased influence of health attributes in self-control challenge choices (i.e. trials in which health and taste attributes were not aligned; $z = 4.18$, $p < 0.001$). Lastly, our multiple regression analyses demonstrated that HRV explains unique variance in choice patterns across participants that is not captured by standard self-reports measuring cognitive regulation of eating behavior.

Conclusions: Heart rate variability is an index of cardiovascular health that has been associated with improved performance in executive function tasks and may reflect an organism's readiness and ability to adapt to changes in the environment. Our results indicate that participants with a greater HRV are better able to flexibly incorporate health into food value computations in order to maintain dietary health goals.

Acknowledgements: This study was funded by the Swiss National Science Foundation grant 140277 and EU FP7 grant 607310.

Risk taking as a complex phenotype: Identifying common and specific neural correlates of risk taking in multiple behavioural paradigms

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Objective: There is an ongoing debate concerning the extent to which tasks commonly used to assess risk taking assess similar or disparate aspects of a complex phenotype. We aimed to contribute to this question by investigating whether 1) individual differences in risk taking generalize across behavioral tasks and self-report measures, and have reliable correlates to 2) functional activations in brain areas associated with risk processing, and/or 3) volumetric brain differences in such areas.

Methods: One-hundred and thirty-three participants completed a one-day lab session that included a battery of behavioural tasks, including described gambles, experienced gambles, balloon analogue risk task (BART), Columbia card task, devil's task, as well as self-report measures of risk taking (e.g., DOSPERT). Further, all participants participated in an MRI session comprising structural scans and functional runs of the BART and a mixed gain/loss gambles task. We investigated activation profiles for both tasks separately as well as in conjunction using the general linear model (all analyses whole brain, FWE=0.05). We also conducted voxel-based morphometric (VBM) analyses of regional grey matter differences and links to performance-based scores on risk taking measures from the MR and lab sessions.

Results: At the behavioural level, correlations between risk taking paradigms were weak, suggesting that different tasks capture significantly different aspects of risk-taking behavior. Nevertheless, analysis of BOLD signal changes in the risk-taking tasks from the MR session confirmed involvement of similar neural representations of risk and value for the two tasks (e.g., bilateral insula, caudate, medial prefrontal cortex). In addition, we found task-specific activation profiles in several regions (e.g., cingulate cortex, ventromedial prefrontal cortex and parietal regions). Individual differences in risk taking in the BART but not gambles task was associated with functional brain differences in the right insula, as well as other regions. Results from VBM analyses suggest that structural brain differences were not associated with individual differences in risk taking in either the two MR tasks or all other measures assessed in the lab session.

Conclusions: Our results suggest that functional, but not structural brain differences as assessed from VBM, can be used to reliably predict individual differences in risk taking behaviour. Overall, our results suggest that different risk taking measures tap into both common and specific components of risk and value processing that contribute to the multifaceted phenotype that is risk taking.

Acknowledgements:
This study was funded by the Schweizer Nationalfonds, Bern, Switzerland and the Max Planck Institute for Human Development, Berlin, Germany.

The role of eye movements in contextual risky choice

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Background: Context effects are defined as changes in preference depending on the set of available options (e.g., Simonson, 1989). They violate traditional axioms of rational choice and the mechanisms leading to their emergence are still under debate. Unlike utility based models of preferential choice, more sophisticated evidence accumulation frameworks like Multialternative Decision Field Theory (Roe, Busemeyer, & Townsend, 2001) are theoretically able to account for these effects.
Recently, visual attention has been ascribed a more constructive and active role in preference formation, leading to the development of attention based models of choice (Krajbich, Armel, & Rangel, 2010). Yet it remains unclear how attentional models perform in the contextual setting and how they compare against other model classes.

Methods: Subjects performed a straightforward incentive compatible three alternative forced choice task between risky gambles that were individually tailored and specifically designed to elicit context effects. Eye movements were recorded throughout the experiment. Choice behavior and eye movements were analyzed psychometrically.
A quantitative model comparison was performed between utility based, connectionist evidence accumulation and attentional models of decision making.

Results: The experiment replicated the attraction effect and demonstrated the compromise effect for the first time in risky choice. Eye tracking data suggest a clear correspondence between visual attention and choice behavior, replicating the gaze cascade effect (S. Shimojo, Simion, Shimojo, & Scheier, 2003). The quantitative model comparison revealed that model performance is superior for models that weigh utility measures with the relative amount of visual attention (i.e., relative dwell time) an option received.

Conclusion: We conclude that visual attention is inherently linked to preference formation in preferential choice and that computational models of decision making can greatly benefit from a higher integration with attentional mechanisms.

References:

Krajbich, I., Armel, K. C., & Rangel, A. (2010). Visual fixations and the computation and comparison of value in simple choice. *Nature Neuroscience*, *13*(10), 1292–1298. http://doi.org/10.1038/nn.2635

Roe, R. M., Busemeyer, J. R., & Townsend, J. T. (2001). Multialternative decision field theory: A dynamic connectionist model of decision making. *Psychological Review*, *108*(2), 370. http://doi.org/10.1037//0033-295X.108.2.370

Shimojo, S., Simion, C., Shimojo, E., & Scheier, C. (2003). Gaze bias both reflects and influences preference. *Nature Neuroscience*, *6*(12), 1317–1322. http://doi.org/10.1038/nn1150

Simonson, I. (1989). Choice based on reasons: The case of attraction and compromise effects. *Journal of Consumer Research*, 158–174.

Loss aversion in effort-based decision making

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Objective: Loss aversion is a well-established phenomenon in human behavior, where our desire to avoid negative outcomes (losses) surpasses our desire to acquire positive outcomes (gains). Yet there is an aspect of these decisions that has received less attention. Acquiring the outcome, regardless of its desirability, nearly always requires some form of effort. A growing body of research is now trying to understand the representation of effort and its neural correlates. One outstanding question is how individuals assess potential increases in effort relative to decreases in effort. We tested the hypothesis that healthy young adults exhibit loss aversion in an effortful reaching movement, meaning that increases in effort are more undesirable than decreases in effort (i.e. effort relief) are desirable. We expected that loss aversion in effort would have a similar magnitude to that seen in classic financial tasks (wherein losses loom 2-3 times larger than gains).

Methods: We examined loss aversion in effort using a movement and decision-making task, where decreased effort (effort relief) was framed as a gain and increased effort was framed as a loss. Subjects performed reaching movements against different levels of resistance (effort) requiring known levels of metabolic expenditure. They then chose to accept or reject different lotteries, each with possibility of performing a less effortful condition and a possibility of performing a more effortful condition, against the certain outcome of performing a medium level of effort. Subjects also performed an equivalent financial task, in which there was a possibility of winning or losing money. We used maximum likelihood estimation to fit subject-specific loss-aversion coefficients, λ, to their choices.

Results: Subjects were loss-averse in the effort-based task ($\lambda_{EFF} = 1.26 \pm 0.09$), and they were significantly more loss-averse in the financial task ($\lambda_{FIN} = 2.52 \pm 0.31$). Our results demonstrate that gains and losses in effort are not valued symmetrically, even in a simple arm-reaching movement. The observed loss aversion in arm-reaching suggests that movement decisions are geared toward avoiding higher effort over acquiring lower effort.

Conclusions: Our findings demonstrate that gains and losses in effort are not valued symmetrically. Even in a simple arm-reaching movement, individuals prefer to avoid investing effort above obtaining effort relief. Understanding these subjective representations of effort will help us better simulate and predict movement decisions for healthy individuals, as well as for clinical populations who may further distort effort valuation, such as in Parkinson's disease.

Acknowledgements:
This study was funded by NSF (CAREER SES 1352632, SES 1230933, CMMI 1200830).

Exploring the role of DLPFC in the interconnection between risk and time preferences using transcranial magnetic stimulation

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This project implies using transcranial magnetic stimulation to study the intertemporal choice process and its interconnection with risk preferences of humans on the individual level.

Individual behavior of agents often implies the making intertemporal choice, i.e. the choice in which various alternatives realize in different time moments. Unlike the present, the future is always uncertain. Hence, intertemporal preferences of people must inevitably be influenced by their risk preferences. The present study aims to determine the role of the prefrontal cortex in making choices of both types. In particular, one of the interesting research questions is which prefrontal brain areas mediate risk attitudes and which are involved in the formation of time preference. Some studies suggest that rDLPFC is responsible for the formation of attitudes towards risk: in Knoch et al. (2006) the deactivation of this brain area led the participants to choose more risky options. At the same time, other studies (Figner (2010)) show that the deactivation of lLPFC induces preferences for immediate gratification, i.e. it affects intertemporal choice. Combining the deactivation of the mentioned brain areas in a single study allows to examine the place that risk attitudes take in the formation of intertemporal preferences.

The novelty and specifics of the study consists in the joint estimation of risk and time preference parameters for each subject with and without TMS. Recent developments in Economics allow to use simple binary choice questions to measure the individual degree of risk aversion and the individual time discounting factor corrected for risk aversion. We study three groups of individuals. Group 1 receives the (offline) TMS of the left PFC, group 2 receives TMS of the right PFC, and group 3 receives sham stimulation. Participants from each group make a series of binary risk and time delay choices. For each participant, the utility function parameters are jointly estimated based on their choices. After that, the estimated parameters are compared between the groups.

The study is exploratory. We expect to confirm previous findings on the lateralised preference formation in the DLPFC. At the same time, we explore whether the deactivation of the DLPFC has an effect on time preference through the change in risk preferences. Independently of whether the answer is “yes” or “no”, the results will be informative of the role of DLPFC in the formation of time and risk preferences.

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Reducing left dlPFC excitability with tDCS impairs dietary self-control

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Objective: Self-control is a critical aspect of successful decision-making as it allows us to maintain a long-term goal, such as being healthy, while avoiding choices that may yield immediate enjoyment but are ultimately inferior for our well being. Neuroimaging studies have identified the dorsolateral prefrontal cortex (dlPFC) as a key correlate of self-control in various choice tasks. Here, we directly test the causal role of left dlPFC in dietary self-control by changing neuronal excitability using transcranial direct current stimulation (tDCS).

Methods: Seventy-three healthy participants (35 female) made dietary choices during a baseline period and while undergoing anodal, cathodal, or sham tDCS over the left dlPFC. Prior to stimulation, participants rated the food items for both taste and health aspects. Based on these ratings, we constructed choice pairs in which choosing the healthier option meant foregoing the more tasty option. Prior to the choice task, participants signed a form stating that they would do their best to choose the healthier option (i.e. use self-control) on every trial. Self-control success was defined as the fraction of times participants chose the healthier, less tasty food item. We examined how tDCS Polarity, Condition (baseline vs. stimulation), participants' body mass index (BMI), and the relative taste and health differences of the food items impacted dietary self-control using generalized linear mixed effects regression.

Results: There was a significant interaction between Condition and Polarity such that receiving cathodal tDCS caused a greater decrease in self-control relative to baseline (mean change = -4.8 %) compared to sham stimulation (sham mean change = 0.6 %; z = -2.644, p = 0.008). There was no significant change in self-control rates for anodal stimulation relative to sham.

Conclusions: Left dlPFC is a critical component of the brain's self-control circuitry. The causal role of left dlPFC in dietary self-control has implications for understanding the neurobiological mechanisms underlying obesity and addictive behavior.

Acknowledgements:
This study was funded by the Swiss National Science Foundation #143443, a Marie Curie International Incoming Fellowship # PIIF-GA-2012-327196, and EU FP7 grant # 607310.

Social expectations reverse the effects of acetaminophen on economic decision-making

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Objective: Originally viewed as just a physical painkiller, recent work has shown that acetaminophen (i.e. paracetamol; active ingredient in Tylenol) also blunts affective evaluations and associated insula activity. Knowing the importance of these processes in social preferences, we hypothesized that social and economic behaviors might also be affected by acetaminophen. Here we used a battery of economic games to demonstrate that acetaminophen has consistent effects on decision-making, but that the direction of the effects depend on whether the individual has high or low expectations.

Methods: A total of 241 undergraduate Ohio State University (OSU) students participated in two studies (122 in Experiment 1; 119 in Experiment 2). In each study, subjects received either an acute 1000mg dose of acetaminophen or placebo, both in liquid vehicle, in a double-blind procedure 1 hour before beginning the critical tasks. In Experiment 1, subjects completed a Trust Game where we measured their expectations for the trustees' behaviors in addition to their actual investments. In Experiment 2, subjects completed an Ultimatum Game where we used sequences of high and low one-shot monetary offers to exogenously manipulate the expectations of the responders. Finally, in Experiment 2, subjects also completed several Trust Games as the trustee and reported their beliefs about how much the investors expected them to return. In both experiments, subjects and their partners received monetary compensation determined by selecting one real decision at random.

Results: Among Trust Game investors, acetaminophen increased investments from subjects with low expected returns from the trustee but decreased investments from subjects with high expected returns. Similarly, in Ultimatum Game responders, acetaminophen increased the acceptance of relatively unfair offers and reduced the acceptance of relatively fair offers. Finally, acetaminophen caused trustees in the Trust Game to return more when they thought the investors expected little in return but to return less when they thought the investors expected a lot in return. Thus across all three tasks, we see that acetaminophen affects economic choices and that its effects are reversed for high vs. low expectations.

Conclusions: Overall, our results demonstrate that acetaminophen has socially important but previously unrecognized dampening effects on how people respond to both financial incentives and disincentives for themselves and for others. Furthermore, our findings highlight what we believe to be a general principle of drug action: that psychological factors can change the behavioral and perhaps clinical effects of drugs.

Neural Correlates of Verbatim and Gist Processing of Risky Choices in Adolescents: A Fuzzy-Tracy Theory Analysis.

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Objective: Understanding the origins of risky decision-making is central to neuroeconomics. Research on fuzzy-trace theory (FTT) has shown that risky decision-making develops from an emphasis on verbatim representations (precise words and numbers) in childhood to an emphasis on gist representations (bottom-line meaning) in adulthood. Adolescents are in transition between these two emphases, but tip toward risk taking when benefits are high and probabilities of harm are low (adults are less likely to trade these off). However, this greater emphasis on verbatim processing has never been demonstrated at the level of the brain.
Methods: Thirty-two adolescents were scanned while completing 60 decision problems (gains and losses involving money, lives, and other dimensions) under 3 conditions predicted (and shown in prior work) to alter processing: verbatim (emphasizing quantitative trade-offs), standard problems, and gist (emphasizing categorical something-nothing contrasts). Choices between risky and sure options, and confidence ratings, were elicited.
Results: Behavioral analyses confirmed that processing was altered as predicted. Moreover, fMRI analyses revealed that adolescents showed greater activation under conditions inducing verbatim processing rather than gist processing, which differs from predominant patterns of activation in adults. When verbatim processing was contrasted with gist processing, the anterior-cingulate cortex (ACC) activation was found across several contrasts (significant when correcting for FWE), both when adolescents made traditional framing choices (risk averse for gains, risk seeking for losses) and when they made opposite choices (which they did more far more often than adults). Adolescents' confidence ratings were also lower in the verbatim than gist condition (i.e., decisional conflict was higher). Finally, bilateral inferior parietal cortex (IPC) activation (again FWE corrected) in areas associated with numerical cognition was also observed for key verbatim-gist contrasts.
Conclusions: These results support FTT's predictions that adolescents should show differential patterns of activation under conditions that induce verbatim rather than gist processing. Verbatim processing emphasizes trading off, which should increase decisional conflict (because expected values were equal for sure and risky options), corroborated by results for confidence ratings and consistent with interpretations of ACC as reflecting cognitive conflict.

Cortical electrohysiological activity underlying decision-making under risk

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Objective: Generation of adaptive behavioral responses is not a passive process solely reliant on sensory evaluation. Rather, it requires active integration of sensory input with internally stored information such as generalized knowledge, previous experience, and goals. For example, variation in individual behavioral preferences likely reflects underlying differences in internally generated neural activity. This active combination of external information and internal activity is a fundamental, but understudied aspect of human decision-making. Brain oscillations have been proposed as a fundamental mechanism whereby activity within and across multiple brain areas is coordinated in the service of adaptive behavior. We recorded electrophysiological activity from the cortical surface of neurosurgical patients engaged in a risk and reward decision-making task to understand the relationship of ongoing neural activity to behavioral and computational aspects of decision-making.

Methods: We recorded local field potentials from the brain of neurosurgical patients who underwent surgery for the treatment of intractable epilepsy using electrocorticography (ECoG) (n=7). ECoG data was recorded from prefrontal cortical areas engaged in goal-oriented decision-making tasks, including orbitofrontal cortex (OFC) and lateral prefrontal cortex (LPFC) while patients engaged in a gambling game.

Results: We found that different aspects of the gambling game generated event-related changes in oscillatory activity across multiple areas and frequency bands. Specifically, we observed that electrodes in a variety of prefrontal locations showed significant increases in high gamma (HG; 70-200Hz) power prior to choice in trials in which patients chose a safe prize over a gamble. A different set of electrodes showed differential HG activation at the time of gamble outcome reveal for behaviorally relevant aspects of the task (e.g. wins vs. losses), indicating that prefrontal regions carry out computations related to different aspects of the task. Cross-frequency coupling analyses revealed that the amplitude of HG was often related to the phase on slower oscillations on the theta frequency band (4-8Hz), suggesting a role for theta oscillations in coordinating local activity over multiple brain areas.

Conclusions: These findings provide evidence that neural activity in LPFC and OFC regions may support cognitive processes underlying value-based decision-making such as cognitive control and reward-related learning, and highlight the role of ECoG recordings in advancing our understanding of the neural basis of risk and reward-related decision-making in humans.

Acknowledgements: Supported by NINDS R37NS21135, NIMH MH098023, R01NS078396 NSF BCS1358907, NINDS NS060993, DARPA SUBNETS, UCI SOM Bridge Fund and the Nielsen Corporation.

Regulation of Desires in Everyday Life Partially Mediates the Relation Between Dopamine and BMI Across the Human Life Span

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Objective: Obesity is a major public health burden in the United States, with rates remaining stubbornly high despite intense attention to the epidemic. While traditional public health approaches focus on reducing caloric intake while increasing expenditure, a growing literature suggests that individual differences in obesity susceptibility – manifesting on both the cognitive and neurobiological levels – offer a new avenue for treatment. Recent research has linked individual differences in human dopamine function and body mass index (BMI), but few studies have systematically explored the psychological mediators between this low-level molecular measure and the high-level cumulative genetic and lifestyle outcome of BMI.

Methods: In the present study, we use [18F]fallypride positron emission tomography (PET) imaging to assess the link between individual differences in dopamine receptor availability and BMI in a sample of healthy adults. Subject age ranged from 23 years to 80 years (M = 43 years, SD = 13) and BMI ranged from 20.7 to 33.1 (M = 25.6, SD = 3.7). We also used a validated experience sampling procedure to collect real-world measures of self-regulation in everyday life. Individuals were surveyed via smartphone up to three times a day for 10 days and asked about the presence and strength of recently experienced desires and whether resistance was attempted and whether it was successful.

Results: Analyses showed a strong positive correlation between dopamine binding potential (BP) in the striatum and BMI. Additionally, striatal dopamine binding potential was significantly associated with the percentage of enacted desires in everyday life. Finally, we also found that the percentage of enacted desires in everyday life partially mediated the relation between dopamine and BMI. All of these results held after controlling for age.

Conclusions: We found that the percentage of desires enacted in everyday life exerted a modest mediating effect on the relationship between dopamine and BMI. This is the first study of which we are aware to combine direct measures of the human dopamine system with a measure of self control outside of the laboratory in daily life. The study identifies dopamine-related intermediate phenotypes, such as desire enactment, as a promising therapeutic target for promoting health behavior across the adult life span.

Acknowledgements:
This study was funded by National Institute on Aging grants R01AG044838 and R00AG042596.

Word Count: 2015

State-dependent valuation and choice: behavioral and physiological interactions between internal state and decision making

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Objective: The value of a reward depends on the internal state of the recipient. However, we know very little about how the physiology of internal state influences subjective values. In the current study, our main aims were to examine the systematic effects of food-deprivation on human decision-making across various tasks, and to establish a correlation between alpha amylase (AA – a salivary physiological marker that distinguish between hunger and satiation states) and decision-making.

Methods: Subjects arrived to the lab for two sessions, *satiation* and *hunger*. In both sessions, subjects were asked to refrain from eating for twelve hours. Upon arrival, subjects reported their current hunger level using a Visual-Analog-Scale (VAS). Thereafter, we collected the first saliva sample from each subject. In the *satiation* session, subjects eat breakfast, whereas in the *hunger* session subjects started the behavioral-tasks without receiving breakfast. The behavioral-tasks included a Risky Binary-Choice task (BC) and an Ultimatum-Game (UG) using money and food (chocolate sweets) as rewards. Furthermore, subjects participated in a Generalized-Axiom-of-Revealed-Preference (GARP) game using only monetary reward. At the end of the behavioral phase, subjects gave a second saliva sample and filled another VAS.

Results: **BC**: We found that internal state has an effect on subjects' preferences towards risk. However, the effect was different for money compared to food rewards. In general, for money trials, hunger makes subjects more certain in their choices and more prone to take risky choices close to indifference (hard choices). On the other hand, for food rewards, when subjects are hungry they tend to be less certain about their choices (noisier choices) and to prefer the risky option less often (vs. the *satiation* session) when the choices are hard (near indifference). **UG**: We found that when subjects are hungry they tend to reject the unfair offers (for food but not for money) more often than under satiation condition. **GARP**: we found that subjects tend to become more consistent when they are hungry compared to satiation. Importantly, this is the first time that anyone has ever demonstrated the effect of changing hunger levels on economic rationality. **AA**: we found a significant elevation of AA levels in *satiation* vs *hunger* state. We also found a significant effect of AA levels on the acceptance rate in UG, on risk preference in BC and on economic violations in the GARP.

Conclusions: In this study, we demonstrate that internal state affects human decision-making in different tasks. Importantly, we showed that alpha-amylase may serve as a physiological marker that can distinguish between internal states and effect behavioral response.

Dorsal anterior cingulate and ventromedial prefrontal cortex have inverse roles in both foraging and economic choice

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Objective: Research has grown increasingly interested in contrasting sequential foraging choices and economic choices between simultaneously presented options. Kolling et al. (2012) [KBMR] proposed that these choice types are subserved by different circuits, with dorsal anterior cingulate (dACC) vs. ventromedial prefrontal cortex (vmPFC) driving foraging vs. economic choice. To support this account, they scanned human subjects while making a foraging choice between exploiting a current offer or swapping for potentially better rewards (Stage 1 of a trial [S1]) or an economic choice between two reward-probability pairs (S2). KBMR found that in S1 dACC primarily tracked the relative value of foraging (RVF), and vmPFC the value of exploiting (especially when choosing to exploit), while in S2 dACC tracked the relative similarity of chosen and unchosen values and vmPFC tracked their relative difference. We recently showed that dACC's role in S1 choices is better described by the difficulty of choosing (i.e., value similarity) than by RVF when correcting for choice biases and testing a sufficiently broad set of RVFs (Shenhav et al., 2014). Here we attempt to rule out a third possibility, that dACC tracks both choice difficulty and RVF. In doing so we address concerns about our study design that may have reduced sensitivity to an RVF effect (over and above a difficulty effect), in particular our use of (a) primarily numeric stimuli, (b) a free response paradigm (rather than an enforced delay to response), and (c) a moderate sample size (N=14). We further test an additional hypothesis regarding vmPFC: that its previously reported role in foraging may also be identical to its role in economic choice, and inverse to that of dACC. Specifically, we hypothesize that this region of vmPFC tracked the relative ease of choosing between the options presented.

Methods: We scanned 31 subjects while they performed KBMR's task, including a response delay but using a wide range of RVFs and suited playing cards as reward-related stimuli.

Results: We find that dACC activity during both task stages is similarly well described by choice difficulty, and find no evidence of an RVF effect over and above this, thus replicating our previous findings. Conversely, we find an inverse pattern in vmPFC, whereby activity during both task stages is associated with the ease of the current choice. The latter finding may reflect a value signal associated with choice ease, relative chosen value, or simply greater time off task prior to the response cue.

Conclusions: Our findings weigh further against the theory that separate neural structures (in particular, dACC vs. vmPFC) subserve foraging versus economic choice.

Acknowledgements: This study was funded by the John Templeton and C.V. Starr Foundations.

References:
Kolling, N., Behrens, T. E. J., Mars, R. B., Rushworth, M. F. S. (2012). Neural mechanisms of foraging. *Science 336*(6077), 95–98.
Shenhav, A., Straccia, M. A., Cohen, J. D., Botvinick, M. M. (2014). Anterior cingulate engagement in a foraging context reflects choice difficulty, not foraging value. *Nature Neuroscience 17*(9), 1249–1254.

The Neural Representation of Money and Prices

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Objective: Economic theory posits that only *real* prices matter, namely, that an increase in price combined with an offsetting increase in money available to the consumer will not change choice behaviour. However, behavioural evidence suggests that this is not the case, and that purely *nominal* changes in prices (changes in the way prices are expressed to a subject which have no actual influence on cost) can influence behaviour, an effect referred to as *money illusion* (Fehr & Tyran, 2001).

Our understanding of how prices and money interact in neural activity is, however, limited. While there is evidence that BOLD activity in MPFC and striatum is positively correlated with the magnitude of monetary rewards (Knutson, 2001) and negatively correlated with explicitly stated prices (Knutson et al., 2007; Weber et al., 2009), it is not known if these two effects are implemented by the same neural mechanism under all conditions. Moreover, recent evidence suggests that while different reward types (food and consumer goods) demonstrate some anatomical localization in the MPFC (McNamee et al., 2013), money rewards do not. This raises the question of whether the encoding of a price of a good is localized to region distinct to that good, or encoded globally as a reduction in a separable representation of "money available".

Methods: Sixteen adult subjects participated in the study. While undergoing a functional Magnetic Resonance Imaging (fMRI) scan, each subject passively viewed bundles of goods in two presentation modes. In "Bundle" runs, subjects viewed bundles consisting of a variable monetary amount, USB key of variable capacity and variable number of chocolate bars. Each good appeared in one of two value-levels - high ($12, 32GB, 2 bars, respectively) or low ($6, 16GB, 1 bar). In "Price" runs, subjects were given $30 to spend in each trial, and were presented with bundles of USB key and chocolate bars with prices which yield a net payoff equivalent to the offers made in the Bundle runs ($18 for high value; $24 for low-value). We analyzed the neuroimaging data using a Region-Of-Interest approach, extracting beta values from the ventromedial prefrontal cortex (vmPFC) and ventral striatum. Additionally, we applied Multivoxel Pattern Analysis (MVPA) to the same regions, in order to identify complex differences in neural activity between the two conditions.

Results: GLM regression coefficients from the ventral striatum were found to be significantly different when subjects viewed bundles that included money payoffs versus bundles with an equivalent price. Furthermore, MVPA results show a statistically different pattern of activation within both vmPFC and striatum between the two conditions.

Conclusions: These results suggest that price information has a value representation within the vmPFC and ventral striatum which is distinct from the representation of monetary rewards, at least under some conditions. Such a distinction provides a possible mechanism for the so-called money illusion; why price increases may not be equivalent to identical decreases in monetary income, suggesting a possible neural mechanism for choice behaviour which exhibits the money illusion.

Human behavior in contextual multi-armed bandit problems

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Objective: Reinforcement learning (RL) models have been successful in explaining human and animal learning and decision-making. However, they have been rarely examined in decision environments with more realistic multi-dimensional alternatives, where the number of states increases dramatically. In such environments RL algorithms learn extremely slowly, failing to exploiting the potential structure of the decision situation. By learning the functional relationship between the dimensions and the value of the alternatives the learning problem can be simplified. We study human behavior in a contextual multi-armed bandit (CMAB) task characterized by multi-dimensional stimuli and propose a new class of RL models that rely on function learning to learn the structure of the decision situation.

Methods: One hundred and forty six subjects participated in the experiment with monetary payoffs. Subject did either a CMAB task where they chose repeatedly between multiple alternatives characterized by two informative features and received outcome feedback on their choices, or a multi-armed bandit (MAB) task where feature information was not presented. The goal was to maximize the total reward and the payoffs of the alternatives were governed by a noisy linear function of feature values. To examine whether participants learned the function, the CMAB task was followed with an extrapolation test phase where in each trial three new alternatives were shown, generated by the same function.

Results: Behavioral analysis showed that participants in the CMAB task outperformed those in the MAB task. On average they earned larger rewards and sampled the alternatives with the highest values more often. In the extrapolation phase choices were not random as one would expect from agents ignoring the feature information – distribution was skewed toward alternatives with high function value. This indicates that participants learned the function and used the feature information in the CMAB task to direct their exploration for promising alternatives. We fitted two classes of RL models – naïve RL models that ignore feature information and RL models that use function learning to learn the structure (FLRL). While the modeling results of the CMAB task are mixed, new FLRL models are able to predict choices in the extrapolation phase much better than naïve RL models .

Conclusions: The new CMAB task brings us closer to realistic high-dimensional decision situations without giving away experimental control. Our results show that exploration is guided by the knowledge of the structure of the environment, however, our modeling results call for development of better function learning based RL models.

Disentangling the effects of stress on neural components underlying the experience of empathy

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Objective: Stress is omnipresent in modern life - both at the workplace and in private. Although there is extensive research on the effects of stress on isolated individuals, little is known on how stress affects social cognition and social decision making. Empathy – i.e., sharing and understanding the emotions of others - represents a particularly important socio-cognitive skill and a crucial prerequisite for successful social interactions.

Methods: We used fMRI to assess effects of stress on neural correlates underlying bottom-up components of empathy (i.e., affect sharing /emotion contagion) and their top-down modulation by perspective taking and cognitive appraisal during an empathy for pain paradigm. Participants (N=75) were randomly assigned to a stress and a control group. Psychosocial stress was experimentally induced in the stress group using a well-established stress paradigm (i.e. Montreal Imaging Stress Test, MIST) while the control group underwent a non-stressful control condition.

Results: When watching painful situations of others, stressed participants showed increased activation in brain areas associated with bottom-up affect sharing and emotion contagion – such as the anterior insula, anterior midcingulate cortex, and primary somatosensory cortex. Furthermore, activation in these areas predicted the amount of money participants shared in a dictator game. However, stressed participants also showed stronger bottom-up responses during situations which were actually not painful for the other, but required cognitive reappraisal and perspective taking. Control participants, however, showed increased lateral orbitofrontal cortex activation in these conditions, and decreased shared pain responses- indicating the engagement of stronger emotion regulation and inhibitory processes.

Discussion: Our results imply that while stress intensifies emotion sharing, this comes at the cost of reducing the ability to flexibly regulate this affective response. While people under stress seem to be more "contaged" by the emotions of others, they show lower abilities to regulate these bottom-up driven affective responses. Moreover, their bottom-up responses have direct effects on prosocial decision making. This has crucial implications for our understanding of how stress affects social cognition and social decision making. It furthermore highlights the importance of assessing the underlying neural mechanisms which explain how stress affects complex social phenomena and behavior.

Acknowledgements: This research is funded by the Federal Ministry of Science and Research (BMWF) Austria; Marietta-Blau grant

Choice is bought by judgment of the eye: Necessary prefrontal contributions to value updating during decision-making

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Objective: Recent work has shown that decisions are biased by the time people spend examining their options. This phenomenon has been taken to reflect real-time "value updating," and has been linked to hemodynamic activity within ventromedial prefrontal cortex (PFC). Here we tested whether this region, or any prefrontal sub-region, is necessary for this decision-making bias in 33 patients with focal frontal lobe damage.

Methods: Patients and matched healthy control subjects provided value ratings for a large set of artworks. Artworks were then paired together based on these ratings and presented in a binary choice task while subjects' eye-movements were tracked. The relative influence of value ratings and visual fixations on subjects' choices were tested for using generalized estimating equations at the trial level, while also controlling for visual saliency. Region-of-interest and voxel-based lesion symptom mapping approaches were used to test where damage was associated with changes in the influence of fixations on choice. Following the choice task, subjects also re-rated a subset of the artworks to assess the internal consistency of their value ratings.

Results: Damage to ventromedial and lateral PFC did not affect fixation-driven value updating compared to healthy controls. However, dorsomedial PFC damage led to an increased tendency to choose items that had been fixated longer. All PFC damaged groups made choices that were consistent with their value ratings, and provided internally consistent ratings when asked to re-rate artworks.

Conclusions: These results argue for a critical and specific role of the dorsomedial frontal lobe in mediating the influence of fixations on value-based choice. Patients with damage to this region behaved as if they were fully discounting the value of options outside the locus of fixation. This interpretation aligns with accounts arguing that this region represents the value of exploring alternative options in foraging contexts. The results also raise important questions about the necessary role of ventromedial PFC for such choices. The findings challenge simple views of ventromedial PFC as necessary for assessing and comparing the values of options.

Acknowledgements: This work was supported by an operating grant from CIHR (MOP 97821), a Fonds de Recherche en Santé du Québec Chercheur-Boursier award to LKF, and a Desjardins Outstanding Student Award to ARV.

Dynamic Constraints on the Distribution of Stochastic Choice

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Objective: I propose that recent advances in modelling the dynamics of decision-making offer a neurobiological foundation to the specification of discrete choice models.

To capture the relationship between time and choice, a general class of Bounded Accumulation Model (BAM) posit the existence of a decision signal for each choice alternative, and model the stochastic evolution of these signals towards a decision threshold. Therefore a BAM predicts which signal hits a threshold first (the choice) and when it hits (the decision time). Of this large model class, the *Drift Diffusion Model* (Ratcliff, 1978) of binary choice is a well-known special case, with recent focus shifted towards models with competing signals that race to a fixed threshold (i.e. *Race* models; Usher & McLelland, 2001; Kiani, Corthell, & Shadlen, 2014).

However in economic applications, data on decision time is not typically reported. This leaves open the question of how such insights can be applied to economic models.

Results: I demonstrate that a BAM implies a form of Random Utility Model (RUM), and characterize how the resulting distribution of stochastic choice is related to the distribution of decision time. Crucially, the implied distribution of random utility incorporates the distribution of decision time, and therefore depends on the specification of the accumulation model. This yields falsifiable statements about the distribution of choice probabilities *even if time data is not observed*.

1) An accumulation model with a fixed decision time (interrogation protocol) yields a Probit model with a variance which decreases in time.

2) In the case of the DDM, I derive properties of the random utility distribution implied by the DDM, show that it is correlated over alternatives, and verify that it still yields the Logit model. Therefore the binary Logit can be derived from a different class of random utility distributions than typically stated in the literature (i.e. McFadden, 1974).

3) For Race models, I demonstrate the variance of random utility depends on observables. This result lies in contrast to a model with constant variance (i.e. the Logit), and implies choice probabilities which depend on both the relative difference *and* the magnitude of observables.

Finally, the econometric implications of these results are explored in a well-known experimental condition for choice under uncertainty (Holt & Laury, 2002). For instance, estimates of common structural parameters, such as the coefficient of relative risk aversion, will be biased. This bias can be corrected using the established results.

Conclusions: Economics and neuroscience model decision-making at different levels of analysis. However, the demonstrated relationship between these two levels implies that advances in neuroscientific modelling can constrain the models that applied economics researchers must consider, and vice-versa.

FREQUENCY-SPECIFIC MODULATION OF RISK, CERTAINTY AND COGNITIVE CONTROL

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Transcranial Alternating Current Stimulation (tACS) is a noninvasive stimulation technique that has been shown to enhance cognitive performance by means of entraining neural oscillations within adjacent cortical structures. For this study, we investigated whether it was possible to influence reward processing and cognitive control by frequency-specific tACS by targeting the bilateral prefrontal cortex. Stimulation was delivered online at 5, 10, 20, 40 Hz on the left and right lateral prefrontal cortex while respondents performed a modified volunteer task switching paradigm, in which gains and losses were granted depending on whether respondents chose to switch or repeat mental sets. This design allowed us to determine whether behavioural measures of cognitive control and risk versus certainty differed with respect to gain and loss domains. Preliminary results revealed a frequency specific modulation of 5Hz tACS that decreased reaction time in risk and switch trials in the loss domain regardless of lateralization. Similarly, 5Hz tACS delivered on the left hemisphere during loss domains led to a significantly higher probability of switching and risk taking after switching in previous trials. These findings support the hypothesis that cognitive control and risk taking are associated via theta activity. Furthermore, post-hoc analysis showed that 20Hz tACS delivered on the left prefrontal cortex significantly modulated reaction time of decisions associated with risk taking in the gain domain. This effect may underline an interference of tACS with response preparation when attempting to seek risky gains. To conclude, our findings support the notion that decision-making be means of risk, certainty and cognitive control can be modulated using tACS.

Keywords: tACS, reward processing, cognitive control, prefrontal cortex, risk, task switching, gain promotion, loss prevention

Support grant: This work is supported with a subsidy granted to the HSE by the government of the Russian Federation for the implementation of the Global Competitiveness Program.

Monetary and Liquid Incentives Combine to Modulate Cognitive Task Performance

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Objective: It is unequivocal that a variety of incentives regularly motivate human behavior. However, few studies have explicitly examined whether and how different types of incentives are integrated in terms of their motivational influence. This study examines the combined effects of monetary and liquid incentives on cognitive processing, and whether appetitive and aversive incentives have distinct influences.

Methods: We introduce a novel task paradigm, in which subjects perform cued task-switching for monetary rewards for varying monetary amounts across trials, with liquid incentives serving as post-trial performance feedback. Critically, the symbolic meaning of the liquid was held constant (indicating successful reward attainment), but the liquid valence was blocked. We utilized this paradigm in two experiments. In experiment 1, forty-two adults (27 females; ages 18-32) performed the cued task-switching paradigm, in which they received appetitive, aversive, or neutral liquid solution as post-trial performance feedback. In experiment 2, thirty-nine adults (18 females; ages 18-25) performed the same task, but with only different appetitive liquids as feedback. All subjects filled out questionnaires in which they rated liquid preferences and motivation for each task condition.

Results: In experiment 1, subjects improved their task performance on trials with greater monetary reward, and the monetary reward additively combined with appetitive liquid feedback. Aversive liquid feedback counteracted monetary incentive effects, particularly during low monetary reward trials, as well as in a subset of participants who tended to avoid responding under these conditions. In experiment 2, subjects received only appetitive liquid feedback, and their task performance was predicted by self-reported motivation and pleasantness ratings. Task performance declined throughout the experiment, especially on trials with low monetary reward.

Conclusions: These findings indicate an integrative relationship between primary and secondary incentives that potentially can be dissociated in terms of motivational value. Subjects may combine the utilities of two rewards to improve performance, but integrate the disutility of costs (aversive liquid) and the utility of benefits (money) during motivational conflict. Furthermore, satiation of an appetitive liquid may cause individuals to devalue the motivational value of a trial. These data suggest that humans integrate values from diverse motivational incentives into a "common currency" to bias decisions, which calls for further investigation of neural mechanisms that underlie incentive integration.

Neural Correlates of the Escalation of Commitment: An fMRI Study

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Objective: Escalation of commitment is common in many software projects. It stands for the situation where managers decide to continue investing in or supporting a prior decision despite new evidence suggesting the original outcome expectation will be missed. Escalation of commitment is generally considered to be irrational. Past behavioural literature has proposed several theories to explain the behaviour. Two commonly used interpretations are self-justification and the framing effect. In this study, we conducted an fMRI (functional Magnetic Resonance Imaging) experiment to explore brain activities associated with human escalation behavior resulting from self-justification and framing effects.

Methods: Two factors (self-justification and framing) were included in a 2x2 within-subject factorial experiment. Eight decision scenarios were designed, four with self-justification and four without. Each scenario consisted of 14 decision messages, 7 positively-framed messages and 7 negatively-framed messages. Twenty-five subjects were recruited. Participants imitated an IS manager and were responsible for managing software projects. Each participant had to complete four sessions in the fMRI machine, receiving 28 decision messages from two scenarios, one with self-justification manipulation and one without, in each session. In each trial, the subject was given a decision message for 10 seconds, followed by a decision response for 4 seconds. Each subject performed a total of 112 trials, broken into four sessions of 28 each.

Results: Behavioral results indicated that self-justification messages increased the subject's continuing intention, but negatively-framed messages resulted in lower continuing intention when self-justification was assumed.

Brain images showed that medial frontal gyrus, superior front gyrus, and anterior cingulate cortex (ACC) were more activated by the self-justification messages, while Inferior frontal gyrus, Insula, medial frontal gyrus, and superior front gyrus were more activated by the negatively-framed decision when self-justification was involved. Four brain regions (Inferior frontal gyrus, Insula, medial frontal gyrus, and superior front gyrus) were found correlated with the subjects' decisions.

Conclusions: We founded that self-justification was the main driver of decision escalation. The framing effect was asymmetric, i.e, positive framing contributed to higher escalation only when self-justification was involved. Main findings are summarized below: (1) self-justification processing was associated with strong activation in self-referencing regions (medial frontal gyrus and superior front gyrus) and conflict monitoring region (anterior cingulate cortex, ACC); (2) the negative framing was associated with strong activation in risk perception regions (Inferior frontal gyrus and Insula) and self-referencing regions when self-justification was involved in the task. No significant framing effect was found when self-justification was not present.

Key words: Escalation of Commitment; Self-justification; Framing effect; fMRI
Acknowledgements: The project was supported by Grant NSC102-2410-H-004-196 -MY2.

The value of honesty: Neural evidence for lie-averse preferences

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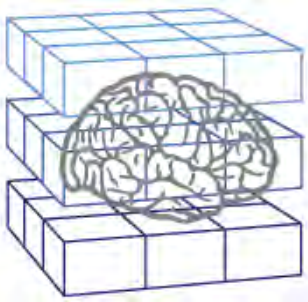
Objective: A wealth of field and laboratory studies have shown that people are often willing to sacrifice their own economic payoffs in the interest of honesty, even in the absence of punishment or reputational threats. However, we know little about the neural mechanisms that allow individuals to resolve competing motives of honesty and self-interest. Here, by combining functional magnetic resonance imaging (fMRI) with a battery of signaling games, a paradigm extensively studied in behavioral economics and evolutionary biology, we investigated the neurobehavioral computations that reflect the separable and integrated weighting between honesty and self-interest motives.

Methods: Thirty-seven healthy, unselected undergraduate students participated in the fMRI study. Each subject made a series of decisions of sending either a true message to an anonymous recipient that sacrifices economic self-interest in favor of honesty, or a false message that satisfies self-interest at the expense of being honest. Behavioral data was used to calibrate individual preferences. Functional imaging data were analyzed using the standard general linear regression where the model-simulated utility for honesty and economic payoffs are included as parametric modulators at the trial-by-trial basis.

Results: Behavioral results of the study confirmed that individuals are willing to forgo their own economic payoffs in order to behave honestly. Notably, the degree of honesty increases when its cost decreases or its benefit increases. Consistent with behavioral findings, neuroimaging results suggested that different brain regions separately encode the expected cost and benefit of a lie during the decision-making process. The expected gain of a lie correlates with the neural activity in the ventromedial prefrontal cortex (vmPFC), whereas the expected cost of a lie is associated with the neural signal in the bilateral anterior insula. Activity in both vmPFC and anterior insular further reflects individual differences in the degree of engaging consequentialists consideration during the decision-making process.

Conclusions: Together, these results demonstrated dissociable neural representations related to the utility weighting between honesty and self-interest motives, suggesting that honest decisions emerge from a value comparison process in the brain. By providing a neural mechanism for lie-averse preferences, we bring the study of honesty into the fold alongside well-studied social dilemmas such as generosity, fairness, and reciprocity.

Acknowledgements:
This study was funded by US National Institutes of Health (R01 MH087692 to P.H.C., R01 DA036017 to B.K.-C. and R01 MH098023 to M.H.), and Hellman Family Faculty Fund (M.H.).



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Session VI
Learning and Memory

Different Neural Mechanisms of Exploratory Behavior in Humans

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Objective: Exploration is a ubiquitous phenomenon in nature. When confronted with making a choice in an uncertain environment, we must decide whether to exploit a known option or explore a less familiar but potentially more rewarding option. In reinforcement learning, this dilemma is known as the trade-off between exploration and exploitation. Previous work on this exploitation-exploration dilemma reveal that orbitofrontal cortex (OPFC) and interparietal sulcus are associated with explorative behavior, whereas activation of regions in the striatum and ventromedial prefrontal cortex (vmPFC) are related to exploitative behavior. However, while this and other studies provide a computational characterization exploration and exploitation, they do not address the large degree of inter-individual differences observed in those studies. It is possible that individual behavioral differences reflect underlying differences in the neural mechanisms implemented by different individuals. One potential source of inter-individual differences could be genetics. Specific genetic polymorphisms have been shown to greatly affect dopaminergic dynamics in many of the areas associated with exploration. By combining fMRI with genotyping and computational modeling we aimed to assess genotype-related differences in BOLD activation patterns associated with exploratory behavior.

Methods: We focused on single nucleotide polymorphisms (SNPs) associated with striatal dopamine function (DARP32) and frontal dopamine function (COMT Val158Met). We predicted that such differences would become most apparent in the frontopolar cortex, which previous studies have associated with exploration. Functional Magnetic Brain Imaging (fMRI) activity was collected from 74 healthy individuals (38 male; mean age 21) using a 3T GE MRI scanner while participants performed a four-arm bandit gambling task. Saliva samples were collected from all participants for genomic DNA extraction and analyzed. A Reinforcement Learning model was implemented to characterize participants' behavioral choices as exploratory or exploitative. A 3-level logistic multilevel model was used to account for each trial's behavioral choice with fMRI activation for each trial (single-trial beta estimate) nested within subject, and subjects nested within genotype.

Results: Multilevel modeling of fMRI (using single-trial betas) and genetic data revealed significant interactions between DARPP32 genotype and BOLD activity in areas of the frontopolar cortex. Specifically, increased fMRI activation in two clusters located in the frontopolar cortex predicted exploration for T-carriers but not for C/C homozygous individuals.

Conclusions: Our work shows that dopamine-related polymorphisms influence the neural mechanisms underpinning exploration in humans. More generally, these results provide evidence for different neural mechanisms implemented by different individuals in exploratory behavior.

Acknowledgements: Supported by CIHR grant #490407 to William A Cunningham, John Templeton Foundation grant #490225 to Adam Anderson, and Varela award # 494241 to Hans Melo.

Reactivation of reward-related patterns from single experiences supports memory-based decision making

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Objective: Rewarding experiences exert a strong influence on later decision making. Learning and decision making research has largely focused on how repeated reinforcement gradually shapes preferences, studying well-learned values built up over many repeated experiences (Daw and Doya, 2006; Schultz, 2006; Rangel et al., 2008). Often, however, our decisions are guided by a single previous experience. While some work has proposed a role for episodes in decision making (Weber and Johnson, 2006; Biele et al., 2009), it is largely unknown whether and how episodic experiences contribute to value-based decision making and how the values of single episodes are represented in the brain. We predicted that people would be able to incidentally encode of the affective value of single episodes. Second, we predicted that reactivation of value associations would allow past episodes guide current decision making.

Methods: We tested these predictions in a behavioral experiment (n=31) and an fMRI experiment (n=29). In a motivated reward task, neutral objects were presented once, incidentally paired with high or low reward. A surprise test for the value associated with the objects followed, asking participants a basic question for adaptive behavior: whether an item was valuable or not. Importantly, the encoding of episode-reward associations in our experiments was implicit. fMRI analyses utilized multivariate analysis tools which provide improved specificity by detecting distributed patterns of brain activity.

Results: In a surprise memory test for the value incidentally associated with the objects, we found that participants could indeed remember the associated level of reward, as evidenced by choice preferences and accurate memory for value. Neurally, we found significant evidence for reactivation of value-related neural patterns of activity at test, such that reward-related patterns from reward anticipation were able to significantly classify patterns of activity at later re-exposure. The strength of this classification effect was positively related to behavioral performance. Further, local searchlight analyses identified significant reactivation in the ventromedial PFC.

Conclusions: Our results demonstrate that single incidental learning experiences can build reliable associations between stimuli and value. Moreover, our findings are the first demonstration that affect-related patterns of brain activity are re-expressed during retrieval. Taken together, our results demonstrate that the reactivation of reward-related neural activity is a mechanism by which episodic memory can guide value-based decision making.

Acknowledgements:
This study was funded by the ERC, grant #2010-AdG_20100407 and DFG, SFB TRR 58 and SFB 936.

The Hippocampus as a Cognitive Map for Model-Based Planning

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Objective:
What is a cognitive map? One prominent perspective frames it as the capacity to represent locations in space, as operationalized by tasks such as the Morris water maze. A separate tradition, using tasks like latent learning, extends this notion to representations of routes and obstacles that enable flexible decision-making through goal-directed planning. Although the hippocampus clearly represents spatial location, little direct evidence corroborates the hypothesis that the same structure supports goal-directed planning. We addressed this gap by probing goal-directed planning and spatial memory in patients with damage to hippocampus and surrounding temporal cortex. We hypothesized that both abilities should be degraded in our patient group and that, if both rely on a common hippocampal substrate, they should be related in subjects with an intact hippocampus but not in those with hippocampal damage.

Methods:
19 patients, who previously underwent unilateral anterior temporal lobectomy (10 right) and 19 healthy controls participated in the study. Groups were matched for age and IQ. Subjects performed a sequential decision-making task (Daw et al, 2011) inspired by latent learning and used to differentiate reliance on habitual “model-free” strategies from goal-directed “model-based” planning. Subjects also performed a virtual reality spatial navigation task (Doeller et al, 2008), similar to Morris water maze, that distinguishes relational place memory, referenced to environmental boundaries and thought to depend on the hippocampus, from "response memory", referenced to a discrete landmark.

Results:
As predicted, patients displayed significantly attenuated place memory but not response memory. Patients were also significantly biased away from model-based and toward model-free strategies on the sequential decision-making task. Comparing the two tasks, place memory performance was correlated with the use of model-based planning strategies in the control group. Importantly, no such correlation was found in the patient group.

Conclusions:
Our result is the first to show a causal role of the hippocampus in goal-directed planning. The finding of improved model-free learning in the patients also speaks to multiple, potentially competing, decision systems in the human brain. Finally, the demonstration that place memory predicts model-based planning

only in the control group suggests that a hippocampal cognitive map may serve as a common neural substrate for flexible behavior during spatial navigation and sequential decision-making, but that following damage to this structure, differential compensatory mechanisms may be employed.

Acknowledgements:
Funded by NIDA, 1R01DA038891

Single-Unit Representation of Value and Prediction Error in Human Amygdala During Reinforcement Learning

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Objective: There is now considerable evidence from animal studies of a role for single amygdala neurons in the encoding of reinforcement-learning related signals during experiential learning. Little however is known about *human* amygdala neurons in value-related processing during experiential learning, and even less about the contribution of amygdala neurons when learning about the value of stimuli through observing the behavior of others. To address these questions we recorded from 91 neurons in the amygdala of 6 participants who were undergoing treatment for epilepsy while they performed a simple reinforcement-learning task with both experiential and observational components.

Methods: Subjects learned the value of color-coded slot machines based on probabilistic monetary outcomes. Learning trials were grouped into two conditions: observational and experiential (2 slot machines per condition). During the observational learning trials, the subject learned the value of two slot machines by observing an actor be presented with slot machine and reward pairings. We explicitly tested learning by interleaving choice trials with the learning trials. To prevent learning during the choice trials, the outcome was not shown but it was added to the subject's final score.

Results: Of the 6 patients, 5 learned the task well, as measured by the proportion of optimal choices (proportion correct > 0.61). Amongst the subjects that learned, the average proportion of correct choices was high (mean = 0.77, SD = 0.15 in experiential condition; mean = 0.72, SD = 0.12 in observational condition). The firing rate of amygdala neurons was correlated with both the unsigned prediction error at reward delivery (n = 16 cells, p=1.1e-16) as well as the machine identity at cue onset (n = 10 cells, p<2.26e-9). To ensure that this effect was due to learning and not visual tuning, we performed a screening task prior to the actual experiment with all of the task stimuli as well as a reversal of the reward distributions for the slot machines halfway through the experiment. Lastly, we noted that a large population of cells (n=28, p=4.44e-16) encoded the task condition (i.e. observational vs. experiential) at reward onset.

Conclusions: Our findings indicate that value signals are represented at the single unit level in human amygdala and they present during both experiential and observational learning. From this, we conclude that the human amygdala may play a general role in tracking the value of stimuli in the world, even those that are learned about vicariously.

NOTES

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