Abstract Book

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Oral Sessions

Friday October 6, 2017

Session I – Value and Choice Mechanisms

08:45 - 09:05 **Neuronal adaptation and optimal coding in economic decisions**

Camillo Padoa-Schioppa[1], Katherine Conen[1], Xinying Cai[2], Aldo Rustichini[3]
[1]Washington University in St Louis, [2]NYU Shanghai, [3]University of Minnesota

During economic decisions, neurons in orbitofrontal cortex (OFC) encode the values of offered and chosen goods. Importantly, their responses adapt to the range of values available in any given context. A fundamental and open question is whether range adaptation is behaviorally advantageous. We develop a theoretical framework to assess optimal coding for economic decisions and we examine the activity of offer value cells in non-human primates. In our framework, optimality for economic decisions corresponds to maximal expected payoff (i.e., maximal chosen value). We show that the firing rates of offer value cells are quasi-linear functions of the offered values. Furthermore, we demonstrate that if response functions are linear, range adaptation maximizes the expected payoff. This is true even if adaptation is corrected to avoid choice biases. Finally, we show that neuronal responses are quasi-linear even when optimal tuning functions would be highly non-linear. Thus value coding in OFC is functionally rigid (linear responses) but parametrically plastic (range adaptation with optimal gain). While generally suboptimal, linear response functions may facilitate transitive choices.

09:10 - 09:30 **Value or a cognitive map? Comparing grid-like conceptual representations and subjective value signals during decision-making**

Linda Yu[1], Sangil Lee[1], Joseph Kable[1]
[1]University of Pennsylvania

Objective: Activity correlated with subjective value has been consistently observed in the ventromedial prefrontal cortex (vmPFC) and a related network of regions during decision-making tasks (Bartra et al., 2013; Clithero & Rangel, 2014; Levy & Glimcher, 2012). Recently, it has been reported that vmPFC contains a grid-like representation of conceptual space (Constantinescu et al., 2016), a kind of "cognitive map" akin to those used in navigation. Could such a conceptual representation underlie value-related vmPFC activity during decision-making tasks? That is, does activity in the vmPFC in decision-making tasks reflect navigation through the conceptual space of choice attributes? We tested this possibility using the analytic techniques of Constantinescu et al. (2016) to look for grid-like representations in a standard decision-making task. Methods: We conducted an analysis analogous to Constantinescu et al. (2016) in a large cohort (N = 71) that completed an fMRI task of delay discounting. Our analysis looked for grid-like conceptual representations in a 2-dimensional attribute space. Taking amount and delay as the dimensions, we modelled activity using a linear combination of sin(6θ) and cos(6θ), where θ is the trajectory angle between the default immediate option and the varying delayed option in the 2-D space. Because of the constraints of the task, these regressors are highly correlated with the subjective value regressor typically used to model vmPFC activity, making it plausible that previous value correlates could be explained by the more recently described grid-like code. We conducted a BIC model comparison between the grid model and the subjective value model. As in Constantinescu et al. (2016), we also compared the performance of a grid model assuming a hexagonal modulation (6θ) to a pentagonal (5θ) or heptagonal (7θ) one, as greater performance of the hexagonal structure would provide the strongest test of a grid-like representation (similar to spatial navigation in the hippocampus, Doeller et al., 2010). Results: Though many regions, including vmPFC and ventral striatum, showed a significant effect of the grid model regressors, there was no region in the entire brain in which the grid model outperformed the

subjective value model in a BIC comparison. Furthermore, unlike the results in Constantinescu et al. (2016), in our context the strong test for grid-like modulation failed: hexagonal grid-like modulation did not outperform pentagonal or heptagonal modulation. Conclusions: Activity in vmPFC during decision-making tasks cannot be explained by a grid-like representation in the conceptual space of choice attributes. Subjective value signals in vmPFC are not merely an epiphenomenon of recently described grid-like neural representations.

09:35 - 09:55 **The neural correlates of (in)consistency**

Vered Kurtz[1], Dotan Persitz[1], Dino Levy[1]
[1]Tel Aviv University

Objective: Consistent behavior is a fundamental notion of neoclassical economic theory. Revealed preference theory (RPT) provides analytic tools to test the inconsistency level of a decision maker. Here, we use RPT and neuroimaging techniques to trace the neural mechanisms that generate inconsistent behavior. To do so, we developed a novel index that measures a trial-level inconsistency score, contrary to the inconsistency indices currently used, that measure an aggregate-level of inconsistency. Using the trial-level index we can measure the severity of each violation and directly trace its neural correlates. This is the first study to measure the neural mechanisms underlying choice inconsistency. Methods: 37 subjects conducted a modification of the task presented by Choi et al.(2007), inside a functional Magnetic Resonance Imaging scanner. On each trial, subjects allocated tokens between two accounts, corresponding to the X and Y axes of a graph. Each account had an equal chance to be casted. Each choice involved choosing a point on a budget constraint of possible token allocations. Prices and endowments varied between trials. Our novel trial-level inconsistency index relies on the Money Metric Index (MMI) method, developed by Halevy et al.(2017). The MMI represents the budget line's adjustment required to relax the inherent incompatibility between two rankings over bundles: the one provided by RPT, as opposed to the one given by the recovered utility function. The recovered utility function over a predetermined set of utility functions is the function for which MMI is minimal. In our novel index, we use the MMI on each trial to provide two trial-level inconsistency indices. First, an in-sample index that measures the adjustment needed in a specific trial, given the selected utility function. Second, an out-of-sample index that recovers, for each trial, the utility function using all other trials. The adjustment needed for the recovered utility function and the bundle chosen at the trial is the index attributed to this choice. We used these two indices as trial-by-trial parametric regressors, and systematically looked for brain areas that track inconsistent behavior. Results: We analyzed data of 8 subjects. We found high heterogeneity in inconsistency index values across subjects, and importantly, between trials within a subject. Neuroimaging data revealed that the BOLD signal in the ventral lateral pre-frontal cortex, dorsal striatum and occipital cortex was correlated with our novel index. Conclusions: These findings suggest specific brain regions are engaged with inconsistent behavior, and perhaps generate subjects' violations of economic rationality.

10:00 - 10:20 **Budget effects on demand elasticities depend on anterior cingulate cortex in rat consumers**

Tobias Kalenscher[1], Sandra Schäble[1], Marijn van Wingerden[1], Yue Hu[1]
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Demand theory can be applied to analyze how animal consumers change their selection of commodities in response to changes in prices of those commodities, given budget constraints. Previous work by us and others has demonstrated that demand elasticities in rat consumers differed between uncompensated budget conditions in which the budget available to be spent on the commodities was kept constant, and compensated budget conditions in which the budget was adjusted so that consumers

could potentially maintain their original consumption pattern. We have recently shown that this budget effect on demand elasticity can be explained by budget-dependent valuation of the commodities above and beyond price-effects on valuation. Here, we hypothesized that rat anterior cingulate cortex (ACC) was necessary to produce the budget effects on demand elasticities. To test this hypothesis, we applied lesions to ACC, or sham lesions, in 24 rats performing an effort task in which they could spend a budget of 80 nose pokes to obtain chocolate or vanilla milk rewards, priced at 2 nose pokes each. All rats generally preferred chocolate over vanilla milk. When the price for chocolate was increased to four nose pokes and the budget was kept constant, their preference for chocolate milk decreased significantly, while the consumption of vanilla rose in response to price decrease. Crucially, changes in chocolate and vanilla demand in sham-lesioned rats in response to price changes were less pronounced when the budget was compensated, replicating our previous results of budget-effects on demand elasticities. By contrast, ACC-lesioned animals reduced their price-related chocolate demand equally strongly in the compensated and the uncompensated budget conditions, suggesting that they failed to integrate the budget constraint into their cost-benefit value computation. We found no main difference in demand elasticities, or baseline preferences, between sham and lesion groups per se, indicating that the lesion effects on the budget-dependence of the rats' demand elasticity was not due to an impaired sensitivity to price changes, baseline reward valuation, or reduced behavioral flexibility. Taken together, ACC-lesioned rats behaved as if they engaged in nominal evaluation of the nose poke costs, but ignored their real value - their purchasing power -, suggesting that ACC integrity seems necessary for computing the real value of the cost component in cost-benefit calculations.

Saturday October 7th, 2017

Session II - Learning

08:45 - 09:05 **Social information impairs reward learning in depressive patients**

Lou Safra[1], Coralia Chevallier[2], Sarah-Jayne Blakemore[3], Stefano Palminteri[2]

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Depression has been shown to be associated with reduced motivation and reward sensitivity. However, former studies have almost exclusively investigated reward processing in non-social contexts, even though impairments in social information processing have been argued to be critical for characterizing depression. Combining these two lines of evidence, we investigated potential interactions between reward-related deficits and social cognitive processes in depression. More precisely, we tested whether depression would be associated with specific social learning deficits. To address this question, we administered a reinforcement-based learning task to two cohorts of subjects (discovery sample: N = 50; replication sample: N = 50). The task involves both a private context (where subjects learned by themselves) and two social contexts: an imitation condition (where subjects could observe the actions of a virtual partner) and a full observation condition (where subjects could observe both the actions and the outcomes of a virtual partner). A general linear model revealed a specific detrimental effect of depression on behavioral performance in the imitation condition ($b = -0.20 \pm 0.09$, $z = -4.56$, $p < .001$), leading to a decrease in performance by 17% between the private and the imitation condition in participants scoring above the clinical threshold of depression. Computational model-based analyses allowed to describe this deficit as a reduction of a private learning in social context, rather than a social learning deficit per se. Using a standard classification algorithm, involving out of sample validation on 100 sample permutations, we assessed the ability of our behavioral task and our computational model to detect participants scoring above the clinical threshold on the depression scale. We found that both the behavioral task and the computational model displayed both good sensitivity (77 ± 2 %) and good specificity (81/84%) to detect clinically depressed participants. To conclude, our results shed new light on

the computational mechanisms underlying the interaction between socio-cognitive and reward learning deficits in depressive patients. In the long term, developing behavioral and computational tools assessing these processes may prove useful to better characterize depressive patients, improve diagnosis and personalize treatments.

09:10 - 09:30 **Neural and behavioral signatures of metacontrol in reinforcement learning**

Wouter Kool[1], Samuel Gershman[1], Fiery Cushman[1]
[1]Harvard University

Many theories in psychology posit a distinction between two systems for choosing actions: A habitual "automatic" system, and a controlled "goal-directed" system. These systems embody different points on an efficiency-accuracy tradeoff that can be formalized using reinforcement-learning (RL) theory. Model-free (MF) RL chooses actions that previously led to reward, which is a computationally efficient but inflexible strategy. Model-based (MB) RL achieves flexibility by planning over a causal model of the environment, which is an accurate but more computationally demanding strategy. Recently, a new paradigm, the two-step task, has been able to distinguish MB from MF contributions to choice. This task has sparked a surge in our understanding of these system's workings. However, there is surprisingly little research on how people choose, from moment to moment, which system to use. Interestingly, prior work has shown that MB control depends on the exertion of cognitive control. A second line of research has shown that cognitive control demands carry an intrinsic effort cost. Combining these insights, we propose a cost-benefit account of metacontrol whereby MB control is only employed when it is associated with enough reward advantage over MF control to offset its costs. Here, we use a novel version of the two-step task in which MB control yields increased reward, which prior versions of this task do not achieve. First, we use this task to test our cost-benefit account with a "stakes" manipulation: on certain trials, a cue signals that subsequent rewards will be amplified. Consistent with our account we saw increased MB control on high-stakes trials in the novel task, but not in the original two-step task, where habit and planning yield equivalent accuracy. Second, we developed a two-step task that varies the complexity of planning from trial to trial, and observed a reduction of MB control when planning costs were high. These results suggest that arbitration between these systems depends on a cost-benefit analysis. We formalize this notion in a new RL model which performs an adaptive form of arbitration. This model is guided by 'controller values' which are updated according to a 'controller prediction error', which integrate the system's costs and benefits. Our model provides a superior behavioral fit compared to previous efforts. In addition, a neuroimaging study reveals a set of regions in frontal cortex, commonly associated with valuation and control, which encode this controller prediction error. Together, our results propose that people flexibly and adaptively integrate the costs and benefits of MF and MB RL in order to guide arbitration between them.

09:35 - 09:55 **Beliefs about bad people are volatile**

Jenifer Siegel[1], Christoph Mathys[2], Robb Rutledge[2], Molly Crockett[1]
[1]University of Oxford, [2]University College London

Objective: Accurately inferring the moral character of others is crucial for avoiding social threats. Putatively "bad" agents command more attention and are identified more quickly and accurately than benign or friendly agents. Such vigilance is adaptive, but can be costly because incorrectly attributing bad character to good people damages existing relationships and discourages forming new ones. How people maintain social relationships despite the potency of negative moral impressions is unknown. Here, we identify a learning mechanism that enables the implementation of forgiving but vigilant strategies in social interactions. Methods: Participants predicted the choices of two "agents" who repeatedly decided whether to inflict painful electric shocks on a victim in exchange for various amounts

of money. The two agents differed substantially in their morality: the "good" agent required more compensation to inflict pain on others than the "bad" agent. Participants also periodically rated their subjective impressions of the agent's morality, and how certain they were about their impression. We used a hierarchical Bayesian learning model to describe participants' evolving beliefs about the character of the good and bad agents. To test the generality of our effects, we examined learning in a non-moral control task where participants predicted the athletic performance of high- and low-skilled agents. Results: Across five studies (total N=792), we show that moral impression formation is explained by an asymmetric Bayesian updating mechanism where beliefs about the morality of bad agents are more uncertain (and thus more volatile) than beliefs about the morality of good agents. This asymmetry could not be attributed to differences in the types of choices that good and bad agents make, and was not observed when people formed impressions of non-moral traits in the absence of moral character information, such as competence. Furthermore, we find that this asymmetry spills over into beliefs about non-moral traits when moral character information is provided: people also form more volatile beliefs about the competence of immoral agents. Conclusions: We demonstrate that inferring bad character destabilizes overall impression formation, affecting not only how people learn about others' morality, but other traits as well. Beliefs about bad character are more volatile, which allows them to be rapidly updated in response to learning an agent is better or worse than expected. Our findings reveal a cognitive mechanism that permits flexible updating of beliefs about threatening others, which could facilitate both vigilance and forgiveness in repeated interactions.

10:00 - 10:20 **Information Prediction Errors in the Human Brain are Valence Dependent and underlie Selective Information Search**

Caroline Charpentier[1], Ethan Bromberg-Martin[2], Tali Sharot[3]
[1]California Institute of Technology, [2]Columbia University, [3]University College London

Objective: Existing models of the brain fail to account for the systematic gap observed between the evidence available to people and the beliefs that they form. One mechanism that can generate such disconnect is selective information search (Golman, Hagman & Loewenstein, 2016): the idea that people are more likely to search for information that supports desired beliefs and actively avoid information that supports undesired beliefs. Here, we show that selective information search is the result of valence-dependent Information Prediction Errors (IPEs) in dopamine-rich subcortical regions. Background: IPEs were recently discovered in macaque monkeys, who sought advance information about the size of reward they were offered (Bromberg-Martin & Hikosaka, 2011). IPEs provide an instructive signal for information-seeking behavior by the same neural circuits and computational code that support reward-seeking. However, they have yet to be documented in humans. In macaques they have only been observed in the context of reward. We postulate that the reward system does not merely treat information as a higher order reward, but rather distinguishes between information that is likely to induce joy and information that is likely to induce sorrow. Methods: We combined fMRI with a behavioral task in which individuals are given repeated opportunities to reveal information about rewards and losses. By dissociating the probability of outcomes from the probability of receiving information about those outcomes, we dissociate RPEs from IPEs. Results: Participants showed a general desire to receive information about their outcomes. Crucially, this preference increased the more likely they were to win but decreased the more likely they were to lose. This pattern was paralleled in nucleus accumbens (NA) and ventral tegmental area/ substantia nigra activity, where IPEs were coded in a valence-dependent manner. This pattern of activity in the NA explained individual differences in valence-dependent information search, while tracking of RPEs did not. Conclusion: Our results provide new insights into the biological mechanism underlying information search. Contrary to previous assumption,

they suggest that dopamine-rich subcortical reward regions do not treat information per se as a higher order reward, but rather may treat the opportunity to receive information about rewards as a reward, but the opportunity to receive information about losses as a loss. As information-seeking is a crucial component of learning and decision-making, this basic finding is important for understanding the neurobiology of human cognition and behavior.

Session III – Strategic Choice

14:15 - 14:35 **Neural computations of strategic decision-making in the volunteer's dilemma**

Seongmin Park[1], Jean-Claude Dreher[2]
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Volunteering is a central feature of human altruism. Benefits from voluntary contribution are threatened by risks to be wasted when one or few volunteers can produce public goods for all. In such volunteer's dilemma (VD), individuals need to make strategic decisions according to their belief about the intention of other members in a group. To investigate mechanisms underlying effective adaptation to different levels of volunteer's dilemma in human decision-making, we used functional neuroimaging and a task in which public goods are generated if the number of volunteers exceeds the stated minimum during finite times of interaction with the same partners. Participants could make more efficient decisions under stronger VD. By systematically deviating their decisions, participants could benefit from public goods more often with fewer contributions. Here, we propose a computational model that predict the voluntary decisions better than other alternative computational models. With this model, we demonstrated that the brain enables to track the action value that maximizes one's payoff in the current state and the state value that takes the future consequences of one's action into account. The activity in ventromedial prefrontal cortex (vmPFC) and insula compute the cost-benefits tradeoff between the expected utilities of each decision option by taking the costs of contribution into account. Moreover, the frontoparietal brain networks encode the expected utility in a longer term. These results suggest that participants not only opt for the decision that can maximize the utility at the current trial but also invest their resources strategically for creating a larger reward in a longer term. The two computational variables were updated by the belief of participants about the probability that one of other members in a group would take free-riding in the following interaction. We found that the activity in the anterior cingulate gyrus (ACCg) tracks the intention of other players by updating the history of interactions. Finally, we found that the dorsomedial prefrontal cortex (dmPFC) where its activity represents decision probability increases the functional connectivity with the brain areas encoding the computational variables at the time of decision-making. Our results provide a neuromechanistic account of what motives people to volunteer and how they are modulated by volunteer's dilemma. Our results might have implications for policy interventions designed to sustain public goods fueled by voluntary contribution.

14:40 - 15:00 **Studying the neural trade-off between human social cooperation and competition through the time dilemma**

M. Andrea Pisauro[1], Elsa Fouragnan[2], Marios Philiastides[1]
[1]University of Glasgow, [2]University of Oxford

In everyday life, our interactions with others entail different motivational goals eliciting both cooperative and competitive states of mind. For example, organising a trip with a friend involves a cooperative behaviour whereas in a game played during the trip, the same friend can become a competitor. Therefore, an optimal behaviour during the whole trip requires the brain to be able to quickly adapt to the social context to adjust decision making. To investigate the behavioural and neural trade-off between competition and cooperation and how it is modulated by social context, we collected fMRI data while

participants played a novel social economic game, which we named the Time Dilemma (TD). The TD game was designed to provide a continuous, dynamical and probabilistic generalisation of the Prisoner's Dilemma. Without deception in the task, couples of unfamiliar players (with one participant inside the scanner and the other outside) made a time-constrained prediction about the location of a random target on a linear space shown on a computer screen and were rewarded according to the precision of their prediction (i.e. proximity to target) and that of the other player, with the closest player being the winner. In each trial, players could choose the middle of the linear space (the position closer to the random target, on average) or move away from it to the left or to the right, thus trading a higher chance of winning (competitive strategy) against a higher reward in case of a win (cooperative strategy), respectively. The continuous nature of the task allowed for a precise parametrisation of the level of cooperation of each player in any trial. To manipulate the social context, we instructed the participants about different reward distributions (i.e. winner-takes-all or 50/50 sharing between winner and loser) implicitly informing them about the risk associated with defecting cooperation. Validating our new approach, participants played more competitively when the risk associated with defected cooperation was high, whereas they exhibit cooperative behaviours when that risk is absent. The extent of this contextual modulation was predicted by the pro-social traits of the participants as estimated through an independently administered questionnaire and reflected in the activation of a network of areas implicated in decision making, evaluation and theory of mind. Taken together, this combination of game theory and fMRI measurements allowed us to compare directly a competitive and a cooperative scenario and provided primary evidence that the brain continuously encodes the social context to set the behavioural and neural trade-off between cooperation and competition.

15:05 - 15:25 **Inferring Individual Goals Using Inverse Reinforcement Learning**

Kelsey McDonald[1], Shariq Iqbal[1], Scott Huettel[1], John Pearson[1]
[1]Duke University

Objective: Most decision tasks in cognitive neuroscience have relied on simplified paradigms with discrete state spaces and known optimal solutions. Yet in real world decision-making, even a simple goal can implicate a vast number of potential actions, and many processes of interest in cognitive neuroscience correspond to tasks for which no normative solution is known. For such cases, inverse reinforcement learning provides a powerful set of techniques for estimating an agent's reward function given its observed behavior. Methods: In this study, humans (n=48) played a "penalty shot" game in which they used a joystick to move a virtual ball from one end of a computer screen to the other, attempting to score against a human confederate goalie. This experimental paradigm allowed us to study strategic decision-making in a task with a simple goal and a continuous action space. We used generative adversarial networks (Goodfellow et al., 2014) to successfully estimate the latent goals of each human subject by modeling the probability of a subject setting a spatial goal at a particular on-screen position. We conditioned these neural networks on the current state of the system (allowing the decision process to be Markov) and on subject identity, allowing for individualized goal estimates. Results: Our model successfully captures the dynamic and highly variable behavior of individual subjects, providing subject-specific estimates of goals and subjective value for each trial. Moreover, by fitting generative networks, we are also able to generate new, artificial trial trajectories that maintain the strategies and biases of individual players. Conclusions: Using an inverse reinforcement learning framework, we infer dynamic, continuous behavior in human subjects during a goal-based decision task. Inferring online subjective value estimates and goals for individual subjects translates to better neural regressors for investigating the spatial and temporal features of goal-driven decision making in humans. This line of research has

implications for the study of individual differences in goal-based decision making as well as the study of decision making across development and in clinical populations.

Sunday October 8, 2017

Session IV – Social Preferences and Influences

08:45 - 09:05 **Accounting for Taste: A Multi-Attribute Neurocomputational Model Explains Divergent Choices for Self and Others**

John Clithero[1], Alison Harris[2], Cendri Hutcherson[3]

[1]Pomona College, [2]Claremont McKenna College, [3]University of Toronto

Objective: Although research suggests that we construct choices for ourselves through the weighted integration of different choice-relevant attribute values, dual-process models posit that separate mechanisms are recruited when choosing on behalf of others. Whether such computations are necessary to explain observed patterns of behavioral or neural response when choosing for others remains unclear. Here we examine this issue by simultaneously fitting a multi-attribute extension of the drift diffusion model (DDM) to choices, response times (RT), and event-related potentials (ERP) from a social decision-making task. Methods: Hungry participants (N=38) with unrestricted diets participated in a choice task in which they selected foods for themselves, a similarly unrestricted eater, and a dissimilar, self-identified healthy eater. Participants made choices while their brain activity was recorded with electroencephalography (EEG). In addition to making food choices, participants also separately rated all food items in terms of taste and health. All DDM estimation using behavioral and neural data was performed using a Bayesian hierarchical framework. Results: We demonstrate that a single computational process, consisting of weighted value integration and accumulation, not only accounts for the choices we make for ourselves and others, but also when and why those choices diverge. Computational modeling revealed different weighting of taste and health attributes depending on the recipient, with increased sensitivity to health information when choosing for the healthy eater. These varying attribute weights were reflected in both behavioral and neural parameters, and explained a prominent pattern in the choice and RT data frequently attributed to dual processes: participants took longer to decide when making different choices for themselves versus others. Additionally, neural value signals were localized to the ventromedial prefrontal cortex and emerged within the same time window for self and others. These signals reflected health and taste preferences of the recipient, and were linked to evidence accumulation in the DDM. Furthermore, we observed little evidence of a late adjustment process in the neural data, further supporting a single computational mechanism. Conclusions: Our results provide a parsimonious explanation for divergent choice and RT patterns in social decision-making based not on a dual process account, but rather on a single neurocomputational mechanism. By jointly considering choices, RT, and neural data, we present new, more precise methods for revealing the neural dynamics supporting our ability to make choices on behalf of others.

09:10 - 09:30 **Gratitude and Pride: Neural correlates of reward attribution to others and oneself**

Ke Ding[1], Dian Anggraini[2], Klaus Wunderlich[1]

[1]Ludwig-Maximilians-Universitaet, [2]Graduate School of Systemic Neuroscience, LMU

Objective: Gratitude and pride are both signals of accomplishment. While complementary, the attribution of the pride is to oneself, gratitude is to another. Acting as an emotional currency for the achievement of reward, gratitude and pride are vital to society, allowing one to build confidence and maintain relationships. Recent neuroimaging studies have highlighted that gratitude expression correlated with BOLD signals in parietal and lateral prefrontal cortex. Despite growing interest in the

neural underpinnings of positive emotions and subjective feelings, we know very little about how these emotions are computationally and neurally represented in the brain. Using computational modeling, functional MRI, and a novel behavioral task inspired by 'Who Wants to be a Millionaire' gameshow, the present research elucidates 1) the unique neural substrates of gratitude and pride in comparison with each other as well as 2) the neural processes on how the brain updates gratitude and pride over time. Method: While undergoing fMRI scanning, we asked subjects (N=30) to perform a trivia task that leads to certain reward whenever they got the correct answer. Every few trials, based on how convinced subjects were about their answers, subjects received pre-recorded advice on the correct answer. They were free to take the advice or stick to their own answers. After given feedback on their answer, subjects were asked to report either "How grateful do you feel towards your audience?" or "How proud of yourself do you feel?" depending on whether they received advice or not. We then modeled the behavioral data using a computational model inspired by reward prediction error. We examined the relationship between the reward obtained on each trial, expected values of chosen answer, certainty, prediction error, and gratitude or pride rating. We also regressed BOLD activity with the outcome of our computational model to test relationship between neural activity and the updating values of gratitude or pride level. Results: We found in a parametric analyses that the magnitude of the subjective gratitude feeling pertained predominantly to neural activities in anterior cingulate cortex (ACC) and temporoparietal junction (TPJ), which has previously been implicated in theory of mind. In contrast, neural activities parametrically correlating with the strength of the feeling of pride was concentrated in the putamen. Using computational modeling, we found common neural correlates related to an updating process of gratitude and pride in medial prefrontal cortex. Conclusion: Our findings delineate the computational mechanisms and neural circuitry for positive emotions that accompany the attribution of getting reward whether it is due to one's own effort or the help of others.

09:35 - 09:55 **Spatial gradient in activity within the insula reflects dissociable neural mechanisms underlying context-dependent advantageous and disadvantageous inequity aversion**

Xiaoxue Gao[1], Hongbo Yu[2], Ignacio Saez[3], Philip Blue[1], Lusha Zhu[1], Ming Hsu[2], Xiaolin Zhou[1]
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Human are capable of integrating context-related information into the decision-making process to further adjust their aversion to inequity at hand, i.e. context-dependent inequity aversion. This context-dependency emerges both when the individual is better off (i.e. advantageous inequity aversion) and worse off (i.e. disadvantageous inequity aversion) than others. Questions remain regarding whether there exist distinct neural representations of context-dependent advantageous inequity and disadvantageous inequity aversion. Here, by combining an interpersonal interactive game that induces interpersonal transgression and a continuous version of the dictator game that enabled us to characterize individual weight on aversion to advantageous inequity and disadvantageous inequity via computational models, we investigated the neural mechanisms underlying context-dependent representations of these two forms of inequity aversion in the interpersonal transgression context. In each round, participants played a dot-estimation task with an anonymous co-player. The co-players received pain stimulation with 50% probability when anyone responded incorrectly. At the end of each round, participants completed an extended version of dictator game (Experiment 1, behavioral) or a monetary binary choice task (Experiment 2, behavioral and Experiment 3, fMRI), which determined payoffs of him/herself and the co-player. Both model-free and model-based results demonstrated context-dependent inequity-aversion: when inflicting pain upon the co-player (i.e. transgression condition), participants cared more about the advantageous inequity and became more tolerant of the disadvantageous inequity, compared with other conditions. Neuroimaging results demonstrated two

distinct types of context-dependent inequity aversion representations, such that the representation of context-dependent advantageous inequity aversion involved left anterior insula, right dorsolateral prefrontal cortex, and dorsomedial prefrontal cortex, while the representation of context-dependent disadvantageous inequity aversion involved left posterior insula, right amygdala and dorsal anterior cingulate cortex. Moreover, the context-dependent representation of inequity aversion exhibited a spatial gradient in activity within the insula, such that anterior parts predominantly represented the context-dependent aversion to advantageous inequity and posterior parts predominantly represented the context-dependent aversion to disadvantageous inequity. These results extended our understanding of decision-making involving inequity and the social function of inequity aversion.

10:00 - 10:20 **Fronto-parietal coupling of brain rhythms during third-party punishment**

Oksana Zinchenko[1], Dmitriy Altukhov[1], Alexey Ossadtchi[1], Anna Shestakova[1], Vasily Klucharev[1]
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Objective: The norm of fair distribution implies rejection of the distribution of goods, which does not take into account the equality of outcomes (Elster, 1989; Kahneman et al., 1986). Importantly, behavioral studies have robustly demonstrated that people not only prefer the fair distribution of outcomes, but also tend to spend their own resources to punish these norm violations at their own cost (Ruff et al., 2013) even though they are not involved directly in unfair situations and act as third parties (Fehr and Fischbacher, 2004). Interestingly, Buckholtz and colleagues (2008) discovered that the right temporo-parietal junction (rTPJ) is activated during third-party punishment while the right dorsolateral prefrontal cortex (rDLPFC) is initially deactivated. Early rDLPFC deactivation is followed by robust rDLPFC activation as subjects go on to make a decision to punish based on assessed responsibility and blameworthiness (Buckholtz et al., 2008). Therefore, an interaction of fronto-parietal networks could drive third-party punishment decisions. Methods: We combined transcranial direct current stimulation (tDCS) and electroencephalogram (EEG) recordings to investigate fronto-parietal coupling of brain rhythms during third-party punishment decisions in Dictator Game. Our results (n=19) suggest that simultaneous anodal tDCS of the rTPJ and cathodal tDCS of the rDLPFC increase third-party punishment of norm violations in comparison with sham stimulation. Next, we investigated fronto-parietal (rDLPFC/rTPJ) coupling of the brain rhythms of 'third parties' in the sham stimulation condition using amplitude-envelope correlation (AEC). Results: Our pilot study (n=11) demonstrated a stronger rDLPFC/rTPJ coupling in the alpha-band (7.5-11.5 Hz) when third parties punished unfair (30:10) distributions of outcomes in comparison with fair (20:20) distributions of outcomes: t=-3,32, df=10, p=0.008. Similarly, we found a stronger rDLPFC/ rTPJ coupling between the theta-band envelopes when third parties observed unfair (30:10) and extremely unfair (40:0) distributions of outcomes in comparison with fair (20:20) distributions: t=2,389, df=10, p=0.038 and t=2,782, df=10, p=0.019, respectively. Conclusion: A stronger fronto-parietal coupling during the observation of selfish decisions was accompanied by a stronger third-party punishment. Overall, our findings further support the hypothesis that the interaction of rTPJ and rDLPFC activity could drive altruistic punishment. Acknowledgment: The study was funded by the Russian Academic Excellence Project '5-100'.

Session V – Risk & Finance

14:15 - 14:35 **Can brain activity forecast stock prices?**

Mirre Stallen[1], Nicholas Borg[2], Brian Knutson[2]
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Objective: In the stock market, fluctuations in prices undoubtedly drive sentiment. Despite popular intuition, however, evidence that sentiment can drive prices is remarkably scarce. In two functional magnetic resonance imaging (fMRI) experiments using a novel stock market decision-making task, we

sought to determine whether activity in neural circuits associated with anticipatory affect could forecast next day movements in stock prices. Methods: In both experiments, participants (Exp1: n=34; Exp2: n=39) viewed trend lines reflecting updates of actual, historical, stock prices while undergoing fMRI. Stocks differed between experiments, but all were listed in the S&P500 index. Participants were not informed about the identity of the stocks or the time period depicted. For each price update, participants decided whether they wanted to invest (i.e. bet that the stock price would increase the next day - if so they gained $1, but if not they lost $1) or not invest (i.e. not bet, in which case they received $0 for that round). Participants viewed price histories of 14 stocks (over 20 days), and made 10 investment decisions per stock (over 10 successive days per stock). Payout was based on performance, and no deception was used. Results: In both experiments, activity in the Anterior Insula (AIns) forecasted inflections in the next day's stock price (price on the next day goes down after an upward day or vice versa). In experiment 1, activity in the Nucleus Accumbens (NAcc) also forecasted price direction (price on the next day goes up after an upward day, or down after a downward day), but this effect appeared to depend on a negative autocorrelation in stock prices that was not evident in experiment 2. The predictive power of AIns and NAcc activity remained significant even after correcting for the effect of participants' own choices and after including standard financial measures used to predict stock market performance (such as slope or volatility). Conclusion: By developing a novel and incentive-compatible stock investment choice task, we were able to demonstrate that neural activity can forecast changes in stock prices above and beyond behavioral choice measures and standard stock performance indicators. These findings build on and extend recent work showing that activity in circuits associated with anticipatory affect (Knutson & Greer, 2008) not only can predict trial-to-trial choice within individuals, but may forecast aggregate choice as well (e.g., Venkatraman et al., 2015; Genevsky et al., 2015).
Acknowledgments: This research was supported by the Neurochoice Initiative, which was funded by a Stanford Neuroscience Institute "Big Ideas" Grant

14:40 - 15:00 **Risk-seeking and loss-seeking in non-human primates is due to convex utility functions and not probability distortion**

Shiva Farashahi[1], Habiba Azab[2], Benjamin Hayden[2], Alireza Soltani[1]
[1]Dartmouth College, [2]University of Rochester

Humans and other animals respond in measurable and predictable ways to risky decisions; our patterns of preferences can be well described by prospect theory. It remains unclear, however, to what extent our particular patterns of preferences are stable and ingrained (possibly even evolved and due intrinsic properties of the brain) or labile, that is, highly contingent on task contexts. Previous research indicates that humans and monkeys both show patterns of risky choice that reflect an inverse-S-shaped transformation in the subjective probability curve. Such work has led to the hypothesis that this distortion is a stable evolved trait. Here we examined two large datasets of macaque risky choices in a computerized token gambling task with gains only and with gains and losses. Consistent with the majority of previous studies, monkeys were risk-seeking but also showed loss-seeking behavior; their behavior was fit by a double convex utility curve that was steeper for gains than for losses. However, they showed weak probability distortion curves that were nearly linear and, to the extent they were not, were more S-shaped than inverse-S-shaped. We further found that preferences were best described by a task-dependent weighted sum of the values of possible outcomes based on reward magnitudes (as opposed to unweighted, which would be normative). These results suggest that estimation of subjective value involves selective processes of reward information according to the task at hand. We propose that this previously unreported weighting process may account for much of the variance observed in preferences across tasks. Overall, these results highlight the diversity of risk attitudes in macaques and

support the idea that risky choices are constructed based on the interaction between task elements and underlying value functions, rather than innate and stable attitudes towards risk. This lability in turn challenges the idea that human-like risk attitudes are stably evolved since we diverged from macaques.

15:05 - 15:25 **Eyes on the prize: risk-promoting sensory reward features result in pupil dynamics consistent with a shift in locus coeruleus-mediated control states**

Mariya Cherkasova[1], Jason Barton[1], Luke Clark[1], A. Jon Stoessl[1], Catharine Winstanley[1]
[1]University of British Columbia

The presence of sound stimuli during slot machine play has been found to increase arousal measured by self-report and skin conductance (Dixon et al, 2014). We have recently demonstrated that the presence of reward-paired sensory features (money images and casino-inspired jingles) promotes risk taking on an economic decision making task. Here, we used pupillometry as a proxy of locus coeruleus-mediated arousal to examine whether risk-promoting sensory feedback increases arousal, as well as to explore possible links between arousal and risk. Healthy volunteers were randomly assigned to perform the decision making task either with or without the sensory feedback features, with concurrent pupil tracking. Aside from the feedback, the two task versions were visually identical. We found that baseline pupil sizes at trial onset were larger in the group without sensory features ($p = .008$). This could not be a luminance-driven effect: the baseline displays were identical, and the feedback display had higher luminance without the sensory enhancement (white screen), which should result in smaller, not larger pupil sizes. Conversely, phasic pupil dilation across decision and feedback anticipation phases of the task (measured as area under the curve with respect to trial baseline), was greater in the presence of the sensory features ($p = .01$). Moreover, the magnitude of decision- and anticipation-related phasic pupil responses on a given trial was significantly associated with the likelihood of taking a risk ($ps \leq .0006$). Changes in pupil dynamics in response to sensory task enhancement are consistent with a shift from a more exploration-dominated to a more exploitation-dominated control state, as proposed by the adaptive gain theory of noradrenergic signalling (Aston-Jones and Cohen, 2005). The former is associated with the tonic mode of locus coeruleus activity, characterized by more enduring but less discriminative responsiveness of cortical neurons. The latter is associated with the phasic mode, characterized by more selective increases in neuronal responsiveness to task-relevant stimuli. Reward-paired audio-visual stimuli, which are ubiquitous in electronic gambling, might shift the balance towards a more exploitation-dominated state, where cortical neurons are selectively responsive to game-related stimuli. Heightened phasic responses to task events characteristic of this state appear to be linked to risk taking.

Session VI – Self-Control and Temporal Discounting

15:30 - 15:50 **White Matter Predicts Mobile Phone Use And Impulsive Decision Making**

William Hampton[1], Henry Wilmer[1], Ingrid Olson[1], Thomas Olino[1], Jason Chein[1]
[1]Temple University

ABSTRACT BACKGROUND: Although smartphones have become an indispensable part of everyday life, for many use of these devices becomes intrusive and addictive. Indeed, some studies have linked technology habits to a trait frequently linked to adverse psychological outcomes?impulsivity. Another line of research has found that impulsivity, as indexed by intertemporal choice measures, is predicted by interindividual variation in the activation and structural white matter connectivity of specific brain regions, such as the ventral striatum. OBJECTIVE: Here we asked whether individual differences in intertemporal preference, impulse control, and reward sensitivity are predictive of the degree to which people engage with their smartphones, and how white matter connectivity among specific brain regions predicts such real-world outcomes. METHODS: In Experiment 1, we captured the aforementioned cognitive traits via behavioral and self-reported measures, and examine their relationship our recently

established measure of Mobile Technology Engagement (MTE). In Experiment 2, we collected diffusion weighted images and conducted probabilistic tractography to investigate the relationship between frontostriatal white matter connectivity and mobile technology usage. We were particularly interested in replicating and extending our previous findings suggesting that specific white matter tracts predict impulsivity, including that connecting the ventral striatum (vSTR) and the ventromedial prefrontal cortex (vmPFC). RESULTS: In line with recent behavioral results, mobile technology engagement was positively correlated with a tendency to discount delayed rewards, as well as reward sensitivity. Consistent with our prior neuroimaging findings, we found that vSTR-vmPFC and vSTR-dlPFC connectivity predicted delay discounting performance. Critically, only vSTR-vmPFC connectivity predicted mobile technology engagement. Taken together, our results both replicate several key findings, and evince a relationship between mobile technology usage, impulsivity, and variation in neural connectivity. We speculate these factors may feed into a positive feedback loop.

15:55 - 16:15 **Neuroanatomy in the vmPFC and dlPFC predicts individual differences in self-control ability of dietary decision-making across tasks**

Liane Schmidt[1], Anita Tusche[2], Nicolas Manoharan[1], Cendri Hutcherson[3], Todd Hare[4], Hilke Plassmann[1]
[1]INSEAD, [2]Computational and Neural Systems California Institute of Technology, [3]University of Toronto, [4]University of Zurich

Background: A large body of literature has investigated the relationship between neural activity patterns and individual ability to regulate affective and cognitive responses. However, the potential structural bases of individual differences in self-control abilities remain understudied. Here, we sought to determine whether anatomical features of individual human brains could be used to predict self-control ability in dietary decisions. Methods: We initially estimated cortical gray matter volume (GMV) using voxel-based morphometry in 123 participants. All of these participants completed a dietary choice task in which they were instructed to focus on either health or taste goals during separate blocks of trials. We quantified the relative influence of taste and health attributes on choice outcomes during the health focus blocks and tested the relationship between these behavioral measures and GMV using multiple regression. Lastly, we tested the generalizability of our results by predicting food choice patterns in a different choice paradigm for a separate sample of 32 individuals using GMV in regions identified in our original sample. Results: Using whole-brain, univariate analyses, we found that greater GMV in regions of the dorsolateral prefrontal cortex and the ventromedial prefrontal cortex was associated with an increased influence of health attributes over taste attributes on food choices during health-focus blocks (SVC pFWE<0.05). Moreover, individual differences in GMV in these two regions also predicted food choice patterns in a separate sample of participants who complete a different task in which they were instructed to up- or down-regulate food cravings, but were not specifically told to consider taste or healthiness (ßdlPFC = -1.62, ste = 0.78, t = -2.05, $p < 0.05$; ßvmPFC = -2.45, ste = 1.15, t = -2.12, $p < 0.05$). Conclusion: Our findings provide novel evidence that individual differences in neuroanatomy within two regions that are critical for valuation and self-control, the dorsolateral and ventromedial prefrontal cortex, predict the ability to self-regulate during dietary choices. Moreover, the associations between GMV and dietary self-control appear to be robust across different dietary choice paradigms suggesting that they could be useful in future efforts to develop diagnostic and treatment strategies.

16:20 - 16:40 **A multiplicative increase in subjective valuation underlies both food and drug craving**

Anna Konova[1], Silvia Lopez-Guzman[1], John Messinger[1], Kenway Louie[1], Paul Glimcher[1]
[1]New York University

Objective: Craving is a specific desire state that biases choice toward the desired object. A vast majority

(90%) reports having experienced craving. In its pathological form craving impacts health outcomes as in addiction and obesity. Yet despite its ubiquity and clinical relevance we still lack a basic neurocomputational understanding of craving. In two studies, in a healthy community sample and in opioid users in treatment, we test the hypothesis that craving is a specific change in an individual's valuation process. In a novel experimental protocol we specifically test the algorithmic nature of this change to more precisely phenotype craving and foster choice-theoretic work. Method: Healthy, 4-h fasted non-dieters (n=45) were offered 1-8 units at a time of three snack foods. We induced craving for one of the snacks by having subjects interact with the snack while recalling its taste and texture. A similar protocol was used to study opioid (heroin and painkiller) craving in recovering users (n=18). Because we could not ethically give opioids, we offered instead personalized opioid use-related goods. These goods were identified as most related to an individual subject's use. To capture dynamics in naturally occurring opioid craving, patients were studied over 3 d (4 h). Subjective valuation for all goods in both studies was quantified repeatedly as a BDM bid. To elicit momentary value, we used a constant hazard rate that could end the experiment suddenly, at which point a single recent bid would be realized. Results: This allowed us to-for each subject, good, and moment-construct a function mapping objective (unit of good offered) to subjective value (the relative increase in value with amount), or utility function. We tested three possible transformations of this function during peak craving: addition (indexed by an intercept change), multiplication (slope change), and exponentiation (curvature change). The distinction among these possibilities is important. Addition would suggest craving is a separable signal independent of the underlying value function. The two non-additive cases would instead suggest craving scales value inputs, linearly (gain control-like scaling) or non-linearly (a fundamental change in value coding), respectively. In health, craving induction selectively increased the craved snack's value. In opioid users, opioid craving increased the value of the opioid use-related goods. For both, the change in valuation during peak craving was best captured by multiplicative scaling of the craved object's value-a linear good-specific increase in the slope of the utility function. Conclusion: These findings offer new ways to quantitatively model craving and a simple and repeatable tool for assessing subjective states in economic terms.

16:45 - 17:05 **Amount and time exert independent influences on intertemporal choice**

Dianna Amasino[1], Nicolette Sullivan[1], Rachel Kranton[1], Scott Huettel[1]
[1]Duke University

Objective: Intertemporal choices (ITC) trade off between smaller, sooner and larger, later outcomes. Hyperbolic ITC models assume that time and amounts are integrated within options and then these option-wise values are compared. However, more recent process models have questioned the assumption of option-wise comparison. Here, we explored the relationship between time and amount attributes in ITC, using a combination of drift-diffusion modeling (DDM) and eye tracking methods. Methods: Participants made binary choices between smaller, sooner and larger, later rewards. A large sample (N=117) enabled us to explore individual differences, and an independent replication (N=100) allowed confirmation of our results. As a baseline for comparison, we fit hyperbolic discount parameter (k) for each participant. Our model of interest is a novel application of the multi-attribute DDM with separate drift speeds for amount and time information. We also use eyetracking to directly measure the attentional mechanisms underlying our modeling results and to explore potential mechanisms not specified in current ITC models. Results: Our DDM revealed that the drift speeds for amount were independent, sharing only minimal variance (r=-0.16, p=ns). However, we found a striking correlation between the difference in drift speeds for amount and time and log k (r=-0.90, p=1.0*10-38), such that those who are more patient (low k) accumulate amount information more quickly than time, and vice

versa for less patient people. Our eyetracking results show that people look more at the attribute for which they have a higher drift speed (r=0.51, p=2.2*10-8) suggesting attention underlies our modeling results. In addition, our eyetracking results show that more patient people use a faster, attribute-wise approach of comparing amounts and choosing the larger whereas less patient participants take longer by integrating time and amount for each option before deciding (r=.61, p=4.7*10-12). Conclusion: Contrary to the canonical assumptions about ITC, our modeling results suggest that amount and time contribute independently to the choice process--and our eyetracking suggests that attention underlies this result. In addition, we find different strategies correlate with ITC preferences, with those who are more patient taking an attribute-wise approach and those who are less patient taking an option-wise approach. This mechanistic understanding of the decision process provides specific attentional targets for future interventions to shift preferences.

Poster Spotlights

Friday October 6, 2017

10:25 - 10:30 **Entropy of Value Representation, Information Maintenance, and the Exploration-Exploitation Tradeoff**

Alexandre Dombrovski[1], Michael Hallquist[2]

[1]University of Pittsburgh, [2]Penn State University

Optimal timing of our actions is often uncertain, but can be learned by responding at different moments in time and evaluating the outcome. One challenge is that outcomes may differ from moment to moment, resulting in a large continuous action space. To investigate how humans resolve this difficult exploration/exploitation dilemma, we developed a reinforcement learning model that estimates time-varying rewards using temporal basis functions. After validating this model in simulations, we observed that people's behavior on a reinforcement-based timing task reflected selective maintenance of the values for frequently chosen actions. This computationally frugal approach preferentially mapped the most valuable part of the environment ('value bump'), largely neglecting the rest and potentially reducing cognitive load during lengthy learning episodes. In simulated worlds and human behavior, selective maintenance of values coupled with stochastic softmax exploration compared favorably to computationally costly uncertainty-driven exploration, which mapped the entire environment more accurately, but typically gained no foraging advantage. Most importantly, softmax exploration is controlled by the entropy (information content) of action values, which unfolds during learning and depends on maintenance. Whereas early sampling under high uncertainty yielded a high-entropy representation, selective maintenance mediated a dramatic contraction of entropy in later learning, accentuating the 'value bump' and accelerating the transition to exploitation. These dynamics were most pronounced in better-performing subjects, in those with higher non-verbal intelligence, and in learnable vs. unlearnable contingencies. In summary, as humans search for optimal action timing, strategic maintenance of action value information controls the exploration/exploitation tradeoff. In this framework, high entropy of value traces reflects high global uncertainty and supports exploration. By contrast, the decline of entropy later in learning mediates exploitation and aversion of uncertain actions.

10:30 - 10:35 **Changing preferences: The neural basis of non-reinforced behavioral change**

Rotem Botvinik Nezer[1], Tom Salomon[1], Yaniv Assaf[1], Tom Schonberg[1]

[1]Tel Aviv University

Introduction The cue-approach task (CAT) has recently been developed to influence preferences (Schonberg et al., 2014). In the task, the mere association of an image with a neutral cue and a speeded button press in one session lasting less than one hour, without external reinforcement or self-control, leads to preference changes lasting months. The underlying mechanisms of CAT are not fully understood and cannot be explained by current theories. Thus, the goal of this study was to investigate the neuroplasticity underlying the behavioral change induced by CAT. Methods Forty participants, randomly assigned to study (n=20) and control (n=20) groups, first subjectively ranked 60 snack food items. Then, to test for changes in individual responses to items, participants were scanned while items were presented each for 2 seconds ('response to snacks' runs). During CAT training (performed outside the scanner), 40 snacks were individually presented, and participants pressed a button as fast as they could when a neutral auditory cue was heard. The cue was consistently paired with 30% of the items in the study group, but inconsistently paired in the control group. Participants re-entered the scanner and performed another 'response to snacks' session. Then they performed a probe phase, where they chose between pairs of items with similar initial rankings (high value-HV/low value-LV), where only one item

was previously paired with the cue (Go item) and one was not (NoGo item). A full cohort of n=40 in each group was pre-registered in Open Science Framework. Preliminary results on n=20 in each group Behavioral: Replicating previous results, participants in the task group (n=20) significantly chose Go over NoGo items in HV ($p<0.001$, logistic regression) but not in LV ($p=0.275$) probe trials. The effect was not present for the control group. Functional: Results are reported for 'response to snacks' runs after versus before training. Data was analyzed using a multi-stage GLM approach with FSL's FEAT. Greater fMRI activation in response to HV Go snacks images, modulated by the proportion of choices during probe, was found in the left angular gyrus of the study but not control group (whole-brain cluster-based GRFT corrected, $z>3.1$, $p<.05$). Discussion Our preliminary results suggest that the change of preferences following CAT relies on attentional processes, related to the observed parietal activations. Cognitive decoding by neurosynth (http://neurosynth.org/decode/?neurovault=CNOFIGAI-49242) revealed term similarity to the medial prefrontal cortex, that has been linked to value encoding. Thus, the mechanism underlying CAT putatively relies on attentional modulation of value.

10:35 - 10:40 **Memory beliefs explain why decisions are biased by memory**

Sebastian Gluth[1], Tehilla Mechera-Ostrovsky[1]
[1]Department of Psychology, University of Basel

Objective: Many preferential choices necessitate retrieving relevant information from memory. Previous work showed that people prefer remembered over forgotten options even when the forgotten options are more likely to be better. In the present, pre-registered study, we tested a mechanistic explanation for the existence of this memory bias: People may believe that they remember options of high value better than options of low value and may thus discount values of forgotten options. Methods: We tested n = 64 participants in a three-stage behavioral experiment. In the first part, participants evaluated a set of food snacks with respect to how much they would like to eat each snack at the end of the study. In the second part, they chose between snacks but had to retrieve the snacks' identities from memory (i.e., snacks were first linked to locations on the screen; during choice, only the locations were presented, and snack identities had to be recalled). In the last part, participants indicated how often they think they had successfully remembered each snack during the second part of the experiment. Logistic and linear regressions were used to quantify the influence of memory on decision making (i.e., the memory bias) and the value-dependency of memory belief, respectively. The main hypothesis was that the coefficients resulting from these regressions would be positively correlated with each other across participants. Results: First of all, we replicated the effect that choices are biased by memory: When choosing between a forgotten and a remembered option, participants had a clear preference for the latter, even when correcting for value and true memory performance ($t(63) = 5.88$; $p < .001$). As predicted, we also found that participants believed to remember better options better, even when correcting for true memory performance ($t(63) = 4.52$; $p < .001$). Third, we confirmed our central hypothesis that the memory bias on choice is correlated with the value-dependency of memory belief ($r = .36$; $p = .002$). In other words, participants who strongly believed to remember good options more often than bad options also exhibited a stronger influence of memory on value-based decisions. Discussion: Our study provides one mechanistic account for the biasing influence of memory on decision making. People believe to retrieve higher-valued options more often, and forgotten options are discounted for the very reason that they are forgotten. Importantly, these findings characterize the memory bias on choice as a (partially) rational choice strategy: If a decision agent believes to remember good options more often, it is adaptive (within the context of this belief) to assign remembered options a higher value.

10:40 - 10:45 **Dopaminergic modulation of the functional connectome and its effects on facial attractiveness judgment**

Gabriele Bellucci[1], Caroline Burrasch[1], Sabrina Strang[1], Thomas Münte[1], Soyoung Park[1]
[1]University of Lübeck
Previous studies have presumed a link between facial attractiveness judgment and the dopaminergic system. However, it is still elusive whether manipulation of the dopaminergic system impacts facial attractiveness judgment. In a within-subject design, we combine pharmacological intervention and functional magnetic resonance imaging to investigate how dopamine changes the connectome of resting-state networks and subsequent attractiveness judgment in 28 female subjects. We hypothesized that pramipexol, a dopamine agonist, modulates both attractiveness judgment and resting-state functional connectivity (RSFC), and that these neural-behavioral modulations will be related. Our results show that acute oral administration of dopamine leads to enhancement of attractiveness judgment independent of attractiveness levels. Further, dopamine-dependent changes in whole-brain RSFC predicted individual differences in attractiveness judgment increase. Connectivity strength of both the cinguloopercular (CON) and sensorimotor networks were mostly increased by dopamine administration. However, the CON was the only network able to significantly predict participants' attractiveness judgments in the dopamine session. Our results suggest that dopamine affects social judgments via modulation of large-scale brain dynamics.

10:45 - 10:50 **Emotional cues alter value-based decision-making and information maintenance in borderline personality disorder: evidence from computational modeling and neuroimaging**

Michael Hallquist[1], Alexandre Dombrovski[2]
[1]Penn State University, [2]University of Pittsburgh
Borderline personality disorder (BPD) often emerges in adolescence and is characterized by emotion dysregulation and interpersonal hypersensitivity. Although decision-making in emotional contexts is impaired in BPD, little is known about the how such effects reflect altered cognitive representation or abnormal neural systems. In this study, 92 participants (47 with BPD symptoms, 45 matched controls) between the ages of 13 and 30 (M = 20.61) completed 8 runs of a reinforcement-based timing task (Moustafa et al., 2008) during an fMRI scan (Siemens Tim Trio 3T; TR = 1.0s, TE = 30ms, 2.3mm isocubic voxels). Runs consisted of fifty trials in which a dot revolved 360° in 4 seconds around a central stimulus (fearful, happy, or scrambled face). Participants pressed a button to obtain a probabilistic reward from a time-varying contingency. Behavioral data were fit using a novel reinforcement learning model (Strategic Exploration/Exploitation of Temporal Instrumental Contingencies [SCEPTIC]; Hallquist & Dombrovski, under review) that represents time-varying contingencies using temporal basis functions, entropy-guided exploration, and selective maintenance of preferred actions under cognitive constraints. Decision signals from SCEPTIC include expected value, complexity of the value distribution (entropy), prediction error (PE), and decay of unchosen actions. Trial-wise decision signals were convolved with a hemodynamic response function and entered in model-based fMRI analyses using FEAT and FLAME1+2 software (FSL 5.0.9). Behaviorally, better performance on the task was associated with greater value-related entropy early in learning followed by reductions in entropy as subjects shifted to exploitation, $r = .42$, $p < .001$. Furthermore, whereas controls tended to revert to high-value actions after a negative PE in the fearful face condition, those with BPD symptoms did not ($p < .001$; no significant PE-related differences for happy or scrambled faces, $ps > .2$), suggesting a disruption of learning from PEs by negative emotion in BPD. In model-based fMRI analyses (voxelwise $p < .001$; cluster $p < .05$), modulation of social cognitive regions including dmPFC, MTG, TPJ, and temporal pole to fearful PEs diminished in with age in BPD, but was relatively stable in controls. The BPD group also had weaker representation of the entropy of learned values in the frontal eye fields and intraparietal sulcus, which may have limited reliance on

entropy to guide exploratory choices. Altogether, these findings suggest that negative emotional cues in BPD may promote more stochastic responding that reflects poor integration of social cognitive regions in prediction error representations from adolescence into young adulthood.

Saturday October 7, 2017

10:25 - 10:30 **Cooperative decision making in the prisoner's dilemma game across the lifespan**

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Are we getting wiser with age? And does this lead to more cooperation as we grow older? Whilst the concept of aging and wisdom is accepted commonly, as the life expectancy is increasing, aging and social decision making has also captured the attention of psychologists, economist and neuroscientist. Older people are claimed to be better able to regulate their emotions, i.e. controlling for their anger, making more economically rational decisions and better at conflict resolution. To study the impact of life experience and age on cooperative decisions in a conflict situation, we recruited 44 young (age: 18 to 27 years), 32 middle aged group (age: 28 to 59 years) 48 elderly (age: 60 to 86 years old) participants. Participants were randomly paired within an age group and played the Prisoner's Dilemma Game (PDG) multiple times with each other, or with a computer. Across blocks the games were played in three environmental (emotional) contexts (negative: randomly losing money, positive: randomly winning money, and baseline environment). Overall young were the least cooperative in comparison to middle-aged and elderly subjects. All participants cooperated more when they played against another human than when they played against a computer but this differential effect was smallest in the elderly, when compared with middle-aged and young. Incurring random monetary losses (relative to winning or baseline blocks) encouraged all participants to cooperate more, as well as increasing cooperative potential (cooperating after being defected). Interestingly, young (relative to middle-age and elderly) participants were most affected by the environmental (emotional) manipulation. The amount of net money earned reflected the cooperation pattern, with participants making more money when playing with human, and in a negative environment. Our finding shows that cooperative behaviour follows a similar pattern across the lifespan. But young subjects were more susceptible to environmental manipulations, especially in a social context, while elderly decisions were less affected by their opponent and were similar whether they were playing against a human or computer. We conclude that with increased age changes in the environment have a weaker impact on overall cooperative decisions.

10:30 - 10:35 **The Habitization of Self-Control**

Gökhan Aydogan[1], Jesse St. Amand[1], Ian Ballard[2], Samuel McClure[1]
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Objective: We face a consistent set of choices every day - what to eat, whether to exercise, how much to spend - for which self-control is required to satisfy long-term goals. As with other executive functions, self-control is generally considered to be an effortful process that is subject to occasional failure. We argue that choices made for regularly occurring decisions leads to the formation of habits, reducing the cost of maintaining a consistent level of self-control. We refer to this process as the habitization of self-control and test predictions of the hypothesis in an fMRI and a behavioral experiment. Methods: Participants completed an intertemporal choice task weekly for five weeks. We tested differences that relate to habit formation and the exertion of self-control between weeks one and five. In two studies, we (1) examined the behavioral effects of habit formation on participants' discount rates as well as their sensitivity to framing effects, and (2) analyzed the neural correlates of habit formation in intertemporal

choice. Results: One consequence of habit formation is that it renders behavior less susceptible to contextual variables that may otherwise bias choice. In study 1 (N=20), we estimated the size of an intertemporal choice framing effect, the date-delay effect (Read et al., 2005), on weeks one and five of the study. We found that habitization reduced the size of the date-delay effect (p0<.05). Several studies have related activity in fronto-parietal cortex to the exertion of self-control. We tested whether the recruitment of fronto-parietal cortex is reduced with habit formation in study 2. fMRI BOLD data were acquired on weeks one and five as participants completed the intertemporal choice task. For both weeks one and five, activity in brain reward areas (ventromedial prefrontal cortex, ventral striatum, and posterior cingulate cortex) was correlated with subjective value. However, dorsolateral prefrontal cortex (dlPFC) activity was negatively correlated with subjective value on week one and this correlation was significantly reduced by week five. By contrast, activity in the dorsal striatum showed increasing correlation with subjective value across sessions. We conclude that habit formation is associated with a shift in the neural locus of delay discounting from the dlPFC to the dorsal striatum. Conclusions: Habit formation in intertemporal choice has two positive effects. First, it decreases susceptibility to contextual variables that otherwise bias preferences. Second, habits permit consistent rates of delay discounting to be expressed even as behavior depends less on brain areas associated with cognitive control (dlPFC) and more on brain areas associated with automatic action selection (dorsal striatum).

10:35 - 10:40 **Adapting choice behavior and neural value coding in monkey orbitofrontal cortex**

Jan Zimmermann[1], Paul Glimcher[1], Kenway Louie[1]
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Behaving organisms face constantly changing environments, requiring nervous systems to encode broad ranges of information efficiently within finite coding constraints. In sensory systems, this problem is widely believed to be addressed by adaptive coding mechanisms like temporal adaptation and spatial normalization. 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 is largely unknown. Here, we present data from a saccadic choice task in which trained monkeys chose between two options differing in reward magnitude and juice type. Blocks of trials were composed of a mixture of "adaptor trials" and "measurement trials". In measurement trials (identical across blocks), monkeys chose between an unvarying reference reward and one of five variable rewards. These trials quantify the monkey's probability of choosing the reference reward as a function of the magnitude of the variable reward; a choice curve. Across blocks, we systematically varied the structure of the adaptor trials to induce narrow or wide background reward environments. While monkeys performed this task, we recorded single-unit activity from orbitofrontal cortex (OFC; area 13). We found that adaptor variability had a significant effect on both choice behavior and neural value coding in OFC. Consistent with an adapting decision mechanism, monkeys exhibited steeper measurement trial choice curves in narrow vs. wide background reward environments. Out of 352 OFC neurons, 103 exhibited a significant ($p<0.05$) modulation by value in the measurement trials (cue or reward period). Consistent with neural adaptation, the strength of value coding was stronger in narrow vs. wide blocks. We then tested if the extent of this coding difference (narrow vs wide) corresponded to the behavioral difference in the choice curve slopes (narrow vs wide) across sessions. In the cue interval, cells that exhibited a significant modulation by value exhibited a strong correlation between neural and behavioral adaptation (cue interval: rho=0.57, p=0.009) while there was no correspondence in the reward period. These results indicate a neurometric-psychometric link between choice performance and value coding in OFC neurons, suggesting a neural mechanism for adaptive decision-making. Ongoing

work will examine whether adapting choice behavior and OFC responses correspond to predictions of divisive normalization-based models of history-dependent decision making.

10:40 - 10:45 **How the sequence of interaction affects strategic choices and value encoding**

Ming-Hung Weng[1], Jen-Tang Cheng[1]
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While strategic interactions and social influence were widely examined, less is however studied on how the sequence of play will impact players' strategic choices. We use functional magnetic resonance imaging (fMRI) experiments to investigate how individuals interact in a specific (Bayesian) type of poker game, which is similar to how athletes compete in pole vaulting, high jumping or weight lifting. Given their state of cards, 1, 2, 3, or 4, participants compete with appropriate card-picking. While each faces increasing chance of success in their state, the one who succeeds with a higher card will win the prize. The same type of games were played between 34 pair of participants under simultaneous or sequential interactions to examine how their choices will be affected by their state (card) along with the sequence of the game as well as their value encoding. Behaviorally participants exhibit distinct choice patterns under different types of game. Unlike in simultaneous games where their strategies are monotone in their states, participants tend to bluff when they have to be the first to reveal decisions especially in worse states. Comparably when they are the latter in making decisions, they are apparently influenced by the opponents' choices. Despite differences in task-relevant activations identified by pairwise contrasts, dissimilar neural representation of their state under distinct sequences of play echoes their behavioral disparities. Stronger BOLD activations are found to covary with better states in dorsal caudate, midbrain, anterior insula and dorsal anterior cingulate cortex only under simultaneous plays. Alternatively, these correlations no longer exist in trials when participants make sequential choices regardless of the order. Nevertheless, similar links are identified between their relative state and BOLD activities in caudate when participants move the last in sequence. In addition, stronger BOLD activities also appear in superior frontal gyrus when participants bluff compared to when they do not.

10:45 - 10:50 **How bottom-up visual salience guides strategic choice in matching and hider-seeker games**

Xiaomin Li[1], Ralph Adolphs[1], Colin Camerer[1]
[1]Caltech

Game theory describes how strategic interactions lead to rewards, and makes predictions about likely strategy choices. It has been known for several decades that, in some games, how strategies are described or mentally represented can influence strategy choices (e.g., Schelling 1960). For example, if two players are trying to coordinate by matching their behavior (e.g., meeting at a common place, without communicating) then the psychological prominence or salience of strategies may influence choice. But there is no good theory of salience. Objective: We explore games in which two players choose a small area in a visual image. Bottom-up visual salience can be predicted from a ?graph-based visual saliency? (GBVS) algorithm. GBVS creates a activation maps using a Markov chain based on dissimilarity, and normalizing by concentrating mass on certain activation maps. The result is an ?end-to-end? algorithm that can take visual images as input and produce a 0-1 salience level for each region in the image. Method: Two players see 129 visual images (chosen from Google images). They play in three conditions (for $)?(1) against a random computer choice, and against another person both (2) with and (3) without feedback. Choices are Gaussian filters around a mouseclick location. If players choose randomly they will match 6.4% of the time. Results: In the matching condition, they successfully match 67% of the time. There is a very strong correlation between saliency and location choices (which is enhanced a bit by feedback). This confirms the long-standing intuition that prominence or salience will

guide choices, but goes further by showing that choices are consistent with a freestanding measure of salience (GBVS) (which is independent of subject gaze and choice). In the hide-seek condition, if location choices match then the seeker player wins. If they mismatch the hider wins. Equilibrium game theory makes a clear prediction here: Players should randomize equally across all locations, and the match rate should be 6.4%. But seekers win 9.6% of the time. This finding replicates a seeker's advantage seen in some behavioral studies. Further analysis suggests an interpretation: The hide-seek game is akin to a visual Stroop task. Hiders choose more salient locations more often (compared to the random benchmark), even though they understand that their goal is avoid the seeker's location. Conclusion: This study provides the first evidence, grounded in many visual cognitive neuroscience studies, about how salience can be measured computationally and can influence behavior in strategic choices. In this case, cognitive neuroscience helps solve a long-standing problem in game theory (i.e., what is salience).

Sunday October 8, 2017

10:25 - 10:30 **How brain rhythms code for variables of decision making: EEG motor beta oscillations reflect reward and risk level associated with an action**

Xingjie Chen[1], Meaghan McCarthy[1], Youngbin Kwak[1]
[1]UMass Amherst

Objective Choosing a course of action in our daily lives requires an accurate assessment of the associated risks as well as the potential rewards. We investigated the neural dynamics of this process by focusing on the neural oscillation patterns reflected in the EEG signals. In particular, we determined whether the beta frequency oscillations involved in motor processing are modulated by the reward and risk level associated with an action. Methods Participants performed a modified version of the Go-NoGo task, in which they earned rewards based on speed and accuracy. The trial started with a presentation of the reward points at stake (high vs. low) and the probability that a Go signal would follow (Go-probability) (trial information period). A Go/NoGo signal was presented afterwards. Faster responses gave larger proportion of the rewards at stake, whereas false alarm resulted in deduction of rewards. EEG was recorded throughout the task. We compared the magnitude of beta desynchronization/synchronization across different reward and Go-probability conditions in the contralateral and ipsilateral motor cortex and the right inferior frontal cortex (rIFG), the brain regions known to be involved in motor initiation/ inhibition. Results During trial information period, we found a significant reward by Go-probability interaction in the contralateral motor cortex. Greater beta desynchronization was found in high compared to low reward condition with high Go-probability. When the Go-probability was low however, indicating greater risks associated with a Go response, beta desynchronization was greater in low compared to high reward condition. No such effects were found in the ipsilateral motor cortex or in the rIFG. After the onset of the Go/NoGo stimulus however, there was a significant effect in the rIFG which is known to be involved in "reactive stopping". Greater beta synchronization was found in high compared to low reward condition with high Go-probability while no such difference was found with low Go-probability. This suggests a greater involvement of the reactive stopping mechanism when changes are required to the prior motor plans. Importantly the power of beta frequency oscillations from the motor cortex and rIFG predicted the response time and false alarm rate, suggesting that changes in beta oscillations across different reward and risk levels reflect how these decision variables shape the motor system which lead to a Go vs. NoGo response. Conclusion Our results suggest that brain rhythms involved in movement planning can code for the expected value of an action by integrating reward and risk level associated with an action. These results provide a mechanistic understanding of how decision variables can guide choice for an action.

10:30 - 10:35 **Risk Attitude as a Perceptual Bias**

Mel Khaw[1], Ziang Li[1], Michael Woodford[1]
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A unified theory of random variation in choices between risky prospects, and departures from risk-neutrality (in both directions), is proposed, paralleling an explanation that has been offered for both stochasticity and bias in perceptual judgments, including judgments of numerosity. According to this view, both the randomness of choices and the average bias result from the fact that choices must be based on a noisy internal representation of the decision situation, rather than on an exact description of it. Noise in the coding of the data that define the problem results in stochastic choice (conditional on the true situation), and an optimal decision rule (from the standpoint of expected wealth maximization) implies behavior that (from the standpoint of an experimenter who knows the true data) appears to violate risk-neutrality. Our assumed model of noise in the coding of potential monetary payoffs is furthermore consistent with evidence on how discrimination thresholds, biases in average estimates, and the variability of estimates across trials scale with increasing stimulus numerosity in the case of numerosity perception. Our experiments document both randomness in subjects' choices when presented repeatedly with the same risky prospects, and the "fourfold pattern of risk attitudes" reported by Tversky and Kahneman. A computational model with only three free parameters (indicating the degree of noise in the internal representations of risky monetary payoffs, certain monetary payoffs, and probabilities, respectively) suffices to allow joint prediction of several hundred moments of the experimental data, characterizing both the average biases in choice in different cases and the degree of variability in choices across trials. It thus provides a functional explanation for several of the main non-normative aspects of behavior summarized by prospect theory, linking them to the need to economize on the neural resources used to represent numerical magnitudes when evaluating risky prospects. The theory also predicts new phenomena (notably, payoff-magnitude-dependence of the apparent distortion of probabilities) not predicted by prospect theory, but confirmed in our experimental data as well as other studies.

10:35 - 10:40 **Reconsidering the description-experience gap: Overweighting of rare events in experienced-based decision under risk**

Shu-Ching Lee[1], Shih-Wei Wu[2]
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Accumulating evidence indicates that, in decision under risk, people tend to distort information about probability associated with potential outcomes. The pattern of distortion tends to change depending on how probability information is revealed to the chooser. When probability is explicitly described to the subjects, subjects tend to overweight small probabilities but underweight moderate to large probabilities. In contrast, when information about probability is acquired through experience, the opposite pattern of distortion was observed (Hertwig et al., 2004). This is often referred to as the description-experience gap. Hills and Hertwig (2010) found that subjects' sampling strategy in the experience-based task affected probability distortion -- subjects who switched more often between lotteries during sampling exhibited larger underweighting of small-probability events. To directly test the impact of switch frequency on probability distortion, we manipulated the switch frequency and randomly assigned subjects to either the high or low frequency condition. We hypothesized that more underweighting of small probability would be observed in the high switch-frequency condition. Another goal of our experiment is to investigate whether subjects will violate the independence axiom of expected utility theory (EUT) in experience-based decision making. Violations of the independence axiom have been attributed to probability distortion and patterns of violations can be used to infer the

shape of the probability weighting function. Utilizing the design in Wu & Gonzalez (1996), we tested the independence axiom in experience-based decision making and estimated the probability weighting function. Analysis of choice data of individual subjects showed that people significantly violated the independence axiom in the high switch-frequency condition (N=86), but not in the low switch-frequency condition (N=49). Surprisingly, based on the pattern of violation, we inferred that subjects overweight small probabilities and underweight large probabilities in the high frequency condition. These results indicate that while switching frequency can affect probability distortion, subjects in experience-based task distort probability similarly to what had been shown in decision from description.

10:40 - 10:45 **The evil of banality: When choosing between the mundane feels like choosing between the worst**

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Objective: Research has shown that our most important decisions tend to provoke the greatest anxiety, whether we seek the better of two excellent options or the lesser of two evils. Yet many of our choice are more mundane, between options we are less invested in, such as selecting from a slate of mediocre but acceptable restaurants. Intuitively these should not be anxiety-provoking. However, given that valuation is reference-dependent, it is possible that we can view below-average options as negative and that choices between them could then engender avoid-avoid conflict, experienced as aversive. While previous studies have exclusively found that low-to-moderate value choice sets decrease anxiety (e.g. Shenhav & Buckner, 2014), here we use a procedure that increases sensitivity to minimal value items and investigate how choices between such items are represented subjectively and neurally. Methods: Across three behavioral studies (Ns=20-26) and one fMRI study (N=30), participants evaluated their liking of common goods, having been encouraged to use the entire rating scale. They then made hypothetical choices between four-item sets, followed by retrospective ratings of the anxiety they experienced during each choice. In the fMRI study, choice trials were interleaved with trials where participants instead appraised the overall value of the choice set. Results: Across all four studies we found that anxiety ratings were greatest both when choosing between the highest value and lowest value choice sets (i.e., a U-shaped effect). We found that this effect can be accounted for by how strongly an individual wants or doesn't want the items in a set, consistent with a motivational salience account (relating to the strength of avoid-avoid or approach-approach conflict). We also demonstrate that this pattern is highly sensitive to the distribution of item ratings: excluding "zero-valued" items based on a willingness-to-pay procedure (as in previous work) artificially censors the lowest-valued items, making this quadratic effect look linear instead. Finally, we found the same salience pattern in brain regions that track choice anxiety (dorsal cingulate, anterior insula); importantly this neural pattern was specific to when participants were choosing (not when they instead appraised the overall set value). Conclusions: Collectively, our findings are consistent with the possibility that choice anxiety scales with the motivational salience of one's choice set, and that such sets can acquire negative value even when in the range of potential gains. They further highlight a surprising way in which valuation methodology affects interpretations of choice-related findings.

10:45 - 10:50 **Short-term plastic changes in the primary sensory cortex elicited by monetary outcomes**

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The dominant neurobiological models of decision-making assume that sensory inputs to decision-making neural networks are stationary. However, many cognitive studies have demonstrated experience-induced

plasticity in the primary sensory cortex. This suggests that repeated decisions may modulate sensory processing. In our study, we tested the hypothesis that a repetitive association of a stimulus with a monetary outcome during a monetary incentive delay (MID) task may lead to changes in plasticity in the primary sensory cortex. We designed an auditory version of the MID task (Knutson et al., 2001, 2000), in which the subjects were punished, based on their responses to a cued, target stimulus. For each trial, the subjects (n = 30) were exposed to one of six "acoustic incentive cues", depicting the monetary contingency of that trial: a small or large potential monetary loss (or break-even). Importantly, in control conditions, the subjects' discrimination of the incentive cues was task-irrelevant. Overall, the subjects participated in two extensive sessions of an audio-version of the MID-task on two consecutive days. We investigated electrophysiological correlates of the experience-induced plasticity of the primary auditory cortex by comparing the mismatch negativity (MMN) evoked by six incentive cues, before and after MID-task sessions. The MMN is an electric brain response, which is automatically elicited by any discriminable change in repetitive sounds or sound patterns. We used a "roving" MMN paradigm to ensure that the MMN changes were entirely due to perceptual learning and could not result from differential states of frequency-specific auditory neurons in the temporal cortex. Following the subjects' extensive MID-task training, we found that the expected monetary loss evoked the significant MMN-amplitude enhancement (the negative deflection increased from -0.56 μV on the first day to -1.6 μV on the second day, Cz, $p < 0.05$), which may reflect a fine-grained stimulus discrimination of stimuli that predicts financial losses. This change in MMN was absent in the control condition. In conclusion, our results demonstrate that a repeated MID-task evokes short-term, plastic changes within the auditory cortices associated with improved stimulus discrimination and involuntary attention toward auditory cues that predict significant monetary losses. The study was supported by the grant 16-18-00065 of the Russian Science Foundation.

Poster Abstracts

Friday October 6, 2017

A - Attention

1-A-1 Exploring antecedents of team performance with neurometric and psychometric assessments: The role of engagement and synchronization on team emerging states and outcomes

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Objective: The aim of this study is to understand the relationship among various emergent properties of teams in regards to team outcomes. Emergent properties relevant for team development and performance of an affective and cognitive nature such as commitment, trust, cohesion, team efficacy, satisfaction, shared mental model (SMM) or transactive memory system (TMS) are measured by psychometric surveys. By using EEG measures both engagement and synchronization are assessed. Previous studies suggest a potential link between EEG measures of individual level of engagement (beta-wave activity in the frontal cortex), synchronization between team members and team performance. However, the understanding of teamwork dynamics, emergent states and desired outcomes in real-world settings remains elusive. Methods: Four teams tasked with developing an innovative and disruptive venture or project, and consisting of 3-4 members per team (master students age 22 to 28, both genders) were assessed in this study. EEG signals were recorded simultaneously from the brains of team members during team discussions (6 x 10 minutes) using mobile dry-electrode EEG headsets in a quiet room. The level of engagement (amplitude of beta-wave in the frontal lobe) of each individual and synchrony (wavelet transform coherence and entropy) among team members were analyzed using Matlab. Organizational psychometric surveys were conducted individually as team members where asked to reflect about team work. Both perceived and actual performance scores were assessed for the teams. Relation between various measures and outcomes were analyzed by non-parametric Spearman's rank correlation method. Results: This exploratory study identifies a series of falsifiable relationships between psychometric and neurometric variables, and advances hypotheses relating to their impact on team performance. For instance, in terms of engagement, teams whose member on average displayed higher beta-wave amplitude in the frontal lobe beta-wave showed higher levels of affective emergent properties in self-survey. In terms of synchronization, higher coherence values indicated greater level of team performance. Conclusions: Assessing emergent properties of teams by neurometric methods complements, both empirically and theoretically, the traditional psychometric approaches aimed at understanding team processes and team performance. Moreover, the practice orientation of management science, where team work in the context of innovative activities is deemed increasingly critical, is enabled by non-intrusive EEG measurements.

1-A-2 Effects of directed attention on stimulus attribute weighting: An ERP study

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Objectives: There is growing evidence that decision-makers assign values to the available options by differentially weighting choice-relevant attributes based on current goals. This process has been linked to event-related potential (ERP) responses ~450-650 ms post-stimulus onset, and is thought to occur via the deployment of attention. However, despite extensive research on the time course of attention and valuation, little work to date has directly examined the temporal dynamics of brain activity when attention is intentionally directed to different stimulus attributes. Methods: We measured brain activity while hungry participants made dietary choices under three different attentional cueing conditions:

responding naturally, focusing on taste, or focusing on health. All three conditions were presented in randomly interleaved blocks within a single session. A prompt at the beginning of each block informed the participant of the current condition. Regardless of the attentional cue, participants were explicitly instructed to respond freely based on their preferences with the knowledge that the decision from a single, randomly selected trial would be implemented at the end of the experiment. Results: Logistic fits to choice curve data revealed significant shifts in attribute weighting depending on the attentional cue, with greater weighting on health during Health blocks and greater weighting on taste in Taste blocks. In line with previous ERP studies of attention, attentional cueing was associated with modulation of the visual P1 component, arising at occipital sensors approximately 100 ms post-stimulus onset. Notably, the P1 response showed a significant linear ordering effect with the largest amplitude for cueing to Health (Taste < Natural < Health), suggesting that focused attention to health versus taste attributes may differentially modulate early perceptual processing. Finally, as in previous studies, we identified neural signals correlated with stimulus value across all three cueing conditions between 450 and 650 ms after stimulus onset. Within this time window there was a significant interaction of health information and attentional cueing consistent with attribute reweighting, reflecting increased neural responses to health information in the Natural and Health conditions relative to Taste. Conclusions: Supporting the role of attentional cueing in choice behavior, these data are broadly in line with an attribute weighting process by the valuation system, with attention modulating neural activity from the earliest stages of decision-making.

B – Choice & Choice Mechanisms

1-B-3 Cognitive mechanisms of decision making in Anorexia Nervosa

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Objective: People make bad choices, leading to adverse health and economic outcomes with broad societal consequences. Individuals with anorexia nervosa (AN) make persistent maladaptive food choices to the point of starvation. The behavioral and cognitive mechanisms of maladaptive choice in AN remain poorly understood. To better understand the characteristics of maladaptive choices in AN and how they differ from a healthy population, we leveraged the time it took to make decisions and eyetracking measures of attention during choice. Methods: Healthy control participants and patients with AN took part in a food choice task that involved a series of choices between pairs of foods that had been rated by each participant at the beginning of the session prior to the choice phase. The difference in ratings between the two foods varied from trial to trial, yielding choice trials that ranged from easy to difficult. Additionally, to test the domain specificity of any differences in choice processes, the same participants performed a perceptual decision task in which they reported the predominant color in a dynamic random dot display comprised of yellow and blue dots. Results: Individuals with AN differed from healthy individuals in specific aspects of choice processes, but not in how value drove the choices themselves. In particular, patients placed the highest value on low fat, low calorie foods compared to healthy controls. Both groups were slower to make decisions when the choice options were closer in value; however, choice difficulty had an even stronger effect on reaction time among patients with AN. Moreover, eyetracking data revealed that healthy participants spent more time viewing items that had higher ratings, whereas patients with AN did not show this gaze bias toward more valued items. These differences between the groups were selective to decisions about food. There were no differences between the groups in the perceptual task (in accuracy, reaction time, or the interaction between difficulty and reaction time). Together, these findings indicate that patients with AN show the same

preference-choice function as controls, but appear to arrive at these choices by engaging different choice processes. In particular, patients with AN were slower than controls when choices were difficult, but were faster than controls when they were not. Conclusions: Compared with healthy individuals, maladaptive choices in AN may be characterized by overactive automatic, habitual processes when decisions are easy and by over-deliberation when decisions are difficult. Additionally, maladaptive decision making in AN may be selective to choices about food rather than representing a generalized deficit.

1-B-4 Changing preferences: The neural basis of non-reinforced behavioral change

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Introduction The cue-approach task (CAT) has recently been developed to influence preferences (Schonberg et al., 2014). In the task, the mere association of an image with a neutral cue and a speeded button press in one session lasting less than one hour, without external reinforcement or self-control, leads to preference changes lasting months. The underlying mechanisms of CAT are not fully understood and cannot be explained by current theories. Thus, the goal of this study was to investigate the neuroplasticity underlying the behavioral change induced by CAT. Methods Forty participants, randomly assigned to study (n=20) and control (n=20) groups, first subjectively ranked 60 snack food items. Then, to test for changes in individual responses to items, participants were scanned while items were presented each for 2 seconds ('response to snacks' runs). During CAT training (performed outside the scanner), 40 snacks were individually presented, and participants pressed a button as fast as they could when a neutral auditory cue was heard. The cue was consistently paired with 30% of the items in the study group, but inconsistently paired in the control group. Participants re-entered the scanner and performed another 'response to snacks' session. Then they performed a probe phase, where they chose between pairs of items with similar initial rankings (high value-HV/low value-LV), where only one item was previously paired with the cue (Go item) and one was not (NoGo item). A full cohort of n=40 in each group was pre-registered in Open Science Framework. Preliminary results on n=20 in each group Behavioral: Replicating previous results, participants in the task group (n=20) significantly chose Go over NoGo items in HV ($p<0.001$, logistic regression) but not in LV ($p=0.275$) probe trials. The effect was not present for the control group. Functional: Results are reported for 'response to snacks' runs after versus before training. Data was analyzed using a multi-stage GLM approach with FSL's FEAT. Greater fMRI activation in response to HV Go snacks images, modulated by the proportion of choices during probe, was found in the left angular gyrus of the study but not control group (whole-brain cluster-based GRFT corrected, $z>3.1$, $p<.05$). Discussion Our preliminary results suggest that the change of preferences following CAT relies on attentional processes, related to the observed parietal activations. Cognitive decoding by neurosynth (http://neurosynth.org/decode/?neurovault=CNOFIGAI-49242) revealed term similarity to the medial prefrontal cortex, that has been linked to value encoding. Thus, the mechanism underlying CAT putatively relies on attentional modulation of value.

1-B-5 Greater sense of psychological ownership enhances endowment effect on risk

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The endowment effect is a tendency to value a good more when owning it. In the past, the effect has been attributed to loss aversion due to a change in reference point. However, several studies have shown that other factors, such as risk and psychological ownership might also influence the magnitude of the endowment effect. In this study, we investigated how these two variables contribute to the endowment effect. Thirty subjects (15 females) participated in a novel lottery decision task. Each subject went

through 72 trials. At the beginning of each trial, the subjects were first endowed with a lottery (also referred to as the "assigned endowment"), and then was given a new lottery that differed from the endowment in both the probability of reward (±5%, ±10%, ±15%) and expected value (0, ±2 coins). The subjects had to decide to either keep the assigned endowment or choose the new lottery. In either case the chosen lottery became the endowment (also referred to as the "chosen endowment") on the next choice problem. The subjects faced up to 6 choice problems on each trial. At the end of the experiment, one trial was randomly selected and the chosen lottery was realized. We analyzed only the choice problems where the two lotteries under consideration had different levels of risk but nonetheless had the same expected value. Here we reported two main findings. First, the frequency of keeping the endowment was modulated by the difference in probability of reward between the endowed and the new lotteries. When reward probability of the endowment was higher than that of the new (endowment being the safer option), the subjects tended to keep the endowment were more likely to do so as the mean probability of the two options increased. On the other hand, when the reward probability of the endowment was smaller than that of the new (endowment being the riskier option), the subjects were less likely to keep the endowment as the mean probability of the two options increased. Second, the probability of keeping the endowment was influenced by the psychological ownership of the endowment. Subjects had a higher tendency to keep the chosen endowment than the assigned endowment. Moreover, the psychological ownership of the endowment also affected the subject's risk attitude. Owning a riskier endowment made the subject more risk averse when the endowment was assigned but more risk seeking when the endowment was selected. In summary, we found that a greater sense of ownership on a risky endowment enlarges the endowment effect and changes risk attitudes.

1-B-6 Dopamine-dependent beta-band value computations during sequential decision making

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Objective To decide optimally, organisms must have a representation of the available options expected values and then select on the basis of these values. It has been shown that these value representations can be observed in motor cortical areas when choices are made in action space. In particular, neural oscillations in the beta band (13 30 Hz) reflect the temporal dynamics of value representations. The neuromodulator dopamine is known to play a key role in both decision making and in the control of beta oscillations. This lead us to hypothesise that dopamine might be involved in sensorimotor cortical beta band value representations. Methods We recorded the MEG of healthy human volunteers while they performed an action-based sequential decision making task under the influence of either the dopamine precursor L-DOPA (100 mg + 25 mg carbidopa), the D2-class antagonist amisulpride (400 mg), or placebo. Behavioural data were modelled using prospect theory. MEG data were beamformed to sensorimotor cortex using an LCMV-beamformer and a contrast of right vs left-hand responses. We used Morlet wavelets for time-frequency decomposition of source-reconstructed data. Multiple linear regression of value parameters against (log) power at each timepoint and each frequency in a trial was used to capture cortical value correlates. Results Replicating previous studies, we first show that, following presentation of the first option on the left side, beta power in contralateral sensorimotor cortex correlates with the value of this option. After presentation of the second option on the right side, this rapidly transitioned to a representation of value difference between the contra- and ipsilateral option. The representation of the first option s value was diminished by L-DOPA and enhanced by amisulpride. Importantly, this effect of dopaminergic medication on cortical value correlates occurred in the absence of main drug effect on overall beta power or on beta desynchronisation associated with motor

preparation. Behaviourally, amisulpride increased choice stochasticity, as captured with the softmax temperature, and increased subjects propensity to alternate responses from trial to trial. Conclusions Our data suggest that dopamine plays a causal role in the temporal dynamics of sensorimotor cortical value representations. This action of dopamine may be a possible mechanism through which dopamine exerts its invigorating effects on instrumental performance and on behavioural flexibility.

1-B-8 Pattern of response time reveals the construction of reward value during adaptive learning and choice

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Every cognitive function involves various processing stages and computations, which are performed by fast synaptic transmissions and neural activity with little delay. Accordingly, the pattern of response time (RT) has long been used to infer neural processes underlying various cognitive functions including working memory, attention, and decision making. However, it is currently unknown if RT is also informative about various stages of value-based choice, and especially how reward values are constructed. To investigate these questions, we analyzed the pattern of RT during a multi-dimensional learning and decision-making task, which can prompt subjects to adopt different learning models. In our experiments, subjects could use reward feedback to directly learn reward values associated with alternative choice options (object-based learning). Alternatively, they could learn values of options' features (e.g. color, shapes) and combine these values to estimate the reward values for individual options (feature-based learning). Firstly, we found RT was strongly modulated by the difference in the value of reward probabilities or subjective values assigned to the two alternative objects on a given trial. Secondly, the number of dissimilar features between the two alternative options had opposite effects on RT depending on whether object-based or feature-based learning was adopted on a given trial and on the relationship between feature values and object values in the environment. Finally, RT reflected the model adopted by the subject on a trial-by-trial basis indicating an overall faster construction of reward value during object-based learning. Altogether, these results demonstrate that the pattern of RT can be used to infer how reward values are learned and constructed during adaptive choice.

C – Computational Modeling

1-C-9 Entropy of Value Representation, Information Maintenance, and the Exploration-Exploitation Tradeoff

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Optimal timing of our actions is often uncertain, but can be learned by responding at different moments in time and evaluating the outcome. One challenge is that outcomes may differ from moment to moment, resulting in a large continuous action space. To investigate how humans resolve this difficult exploration/exploitation dilemma, we developed a reinforcement learning model that estimates time-varying rewards using temporal basis functions. After validating this model in simulations, we observed that people's behavior on a reinforcement-based timing task reflected selective maintenance of the values for frequently chosen actions. This computationally frugal approach preferentially mapped the most valuable part of the environment ('value bump'), largely neglecting the rest and potentially reducing cognitive load during lengthy learning episodes. In simulated worlds and human behavior, selective maintenance of values coupled with stochastic softmax exploration compared favorably to computationally costly uncertainty-driven exploration, which mapped the entire environment more accurately, but typically gained no foraging advantage. Most importantly, softmax exploration is controlled by the entropy (information content) of action values, which unfolds during learning and

depends on maintenance. Whereas early sampling under high uncertainty yielded a high-entropy representation, selective maintenance mediated a dramatic contraction of entropy in later learning, accentuating the 'value bump' and accelerating the transition to exploitation. These dynamics were most pronounced in better-performing subjects, in those with higher non-verbal intelligence, and in learnable vs. unlearnable contingencies. In summary, as humans search for optimal action timing, strategic maintenance of action value information controls the exploration/exploitation tradeoff. In this framework, high entropy of value traces reflects high global uncertainty and supports exploration. By contrast, the decline of entropy later in learning mediates exploitation and aversion of uncertain actions.

1-C-10 A forward likelihood approach for improving the estimation of free parameters in the Drift-Diffusion Model

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A large number of studies have proposed that the Drift-Diffusion Model (DDM) of choice, and its variants, provide a simple computational description of the algorithms used to make a large number of simple decisions. This is based on the fact that this class of models has been able to produce reasonably accurate descriptions of how choices, reaction times, and fixations are related to each other and to exogenous trial parameters, in a wide range of tasks. A difficult step in those studies is the estimation of a small number of free parameters to find the ones that explain the observed data best. In most studies, the estimation is computationally very expensive since they approximate the likelihood of the observed data, as a function of the free parameters, by simulating the model thousands of times and then counting the frequency with which the outcomes match the observed data. We propose an alternative method to estimating the free parameters which relies on computing only the probability of the actual observed data and bypassing the need for the additional simulations. Our approach provides two key advantages over the alternative widely used method: a smaller number of experimental trials is needed in order to obtain comparable estimation accuracy, and the execution time of the estimation algorithms is substantially reduced. Open source code with an implementation of the algorithm is available in GitHub. Although the study and code are focused on the class of DDM models, the methods can also be extended to other probabilistic cognitive models that are computationally costly to estimate.

E – Emotion & Affect

1-E-11 Emotional cues alter value-based decision-making and information maintenance in borderline personality disorder: evidence from computational modeling and neuroimaging

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Borderline personality disorder (BPD) often emerges in adolescence and is characterized by emotion dysregulation and interpersonal hypersensitivity. Although decision-making in emotional contexts is impaired in BPD, little is known about the how such effects reflect altered cognitive representation or abnormal neural systems. In this study, 92 participants (47 with BPD symptoms, 45 matched controls) between the ages of 13 and 30 (M = 20.61) completed 8 runs of a reinforcement-based timing task (Moustafa et al., 2008) during an fMRI scan (Siemens Tim Trio 3T; TR = 1.0s, TE = 30ms, 2.3mm isocubic voxels). Runs consisted of fifty trials in which a dot revolved 360° in 4 seconds around a central stimulus (fearful, happy, or scrambled face). Participants pressed a button to obtain a probabilistic reward from a time-varying contingency. Behavioral data were fit using a novel reinforcement learning model (Strategic Exploration/Exploitation of Temporal Instrumental Contingencies [SCEPTIC]; Hallquist & Dombrovski, under review) that represents time-varying contingencies using temporal basis functions, entropy-guided exploration, and selective maintenance of preferred actions under cognitive constraints. Decision signals

from SCEPTIC include expected value, complexity of the value distribution (entropy), prediction error (PE), and decay of unchosen actions. Trial-wise decision signals were convolved with a hemodynamic response function and entered in model-based fMRI analyses using FEAT and FLAME1+2 software (FSL 5.0.9). Behaviorally, better performance on the task was associated with greater value-related entropy early in learning followed by reductions in entropy as subjects shifted to exploitation, $r = .42$, $p < .001$. Furthermore, whereas controls tended to revert to high-value actions after a negative PE in the fearful face condition, those with BPD symptoms did not ($p < .001$; no significant PE-related differences for happy or scrambled faces, $ps > .2$), suggesting a disruption of learning from PEs by negative emotion in BPD. In model-based fMRI analyses (voxelwise $p < .001$; cluster $p < .05$), modulation of social cognitive regions including dmPFC, MTG, TPJ, and temporal pole to fearful PEs diminished in with age in BPD, but was relatively stable in controls. The BPD group also had weaker representation of the entropy of learned values in the frontal eye fields and intraparietal sulcus, which may have limited reliance on entropy to guide exploratory choices. Altogether, these findings suggest that negative emotional cues in BPD may promote more stochastic responding that reflects poor integration of social cognitive regions in prediction error representations from adolescence into young adulthood.

1-E-12 Effects of loss aversion on neural processing of decision outcomes: an event-related potential study.

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Loss aversion is the tendency to prefer avoiding losses over acquiring wins of the same amount. Previous studies showed that loss aversion is associated with greater autonomic and cerebral responses to monetary losses compared to wins. Feedback-related negativity (FRN) is an electrophysiological response to choice outcomes, manifesting as an increased neural signal for loss compared to win feedback. Complete evaluation of decision outcomes often depends on comparisons between chosen and unchosen options. The present study investigated the neural and temporal underpinnings of loss aversion and its effects on feedback potentials, both for chosen and for unchosen outcomes. A monetary gambling task was used to assess loss aversion in 27 healthy participants. This task involved choices between a sure outcome and an uncertain (i.e., 50% probability) win or loss of variable amounts. Loss aversion, risk aversion and choice sensitivity were evaluated using non-linear parametric fitting of choice data. Electroencephalographic (EEG) activity was recorded continuously using a 128-channel EGI (Electrical Geodesics, Inc., USA) system. FRN was evaluated as the difference in electrical potentials between loss and win outcomes. The amplitude of FRN in the latency interval 364-438 ms in central-parietal midline electrodes correlated with individual loss aversion values. The FRN potential was modelled by an equivalent current source dipole located in the posterior cingulate cortex (PCC). Source activity in PCC also correlated with individual loss aversion values. There was no significant difference in feedback potential amplitudes between unchosen wins and losses. Results suggest an influence of loss aversion on the neural processing of decision outcomes. Individual loss aversion differences are reflected as a relatively stronger negative shift on the electrocortical potential for loss averse participants. PCC appears to mediate outcome evaluations of economic decisions by amplifying FRN, particularly for individuals exhibiting high loss aversion.

1-E-13 Neural circuits supporting incentivized inhibition

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Control over the impulse to grab incentives belies behavioral choice. While distinct and competing

circuits in the brain may drive versus inhibit impulses, interactions between these circuits are not well understood in humans. Previous research has focused on the role of the right ventrolateral prefrontal cortex (VLPFC) in inhibiting ongoing motor responses. However, separate research implicates the nucleus accumbens (NAcc) and anterior insula (AIns) in promoting and prohibiting incentivized behaviors. In this study, we designed a novel task to characterize the structure and function of neural circuits supporting incentivized inhibition. Individuals performed a monetary incentive delay inhibition task in which cued monetary incentives and subsequent motor response requirements were independently manipulated on a trial-to-trial basis. Individuals performed this task while undergoing functional magnetic resonance imaging, followed by a structural diffusion-weighted imaging scan. Behaviorally, high incentives improved responses to obtain money ($t(33) = 4.57$, $p < 0.0001$), but the same incentives impaired response inhibition ($t(33) = -3.71$, $p < 0.001$). Structurally, individual differences in the coherence of a newly-characterized white-matter tract connecting the AIns and the VLPFC were positively associated with incentivized inhibition performance ($\beta = -0.37$, $p = 0.03$), as was coherence of a tract from the right AIns to the NAcc ($\beta = 0.42$, $p = 0.01$). Functionally, right AIns and VLPFC activity were positively associated with incentivized inhibition performance, however NAcc activity predicted failures to inhibit ($\beta = -2.41$, $p < 0.05$). Further, right VLPFC activity mediated the association between AIns-VLPFC tract coherence and incentivized inhibition performance (bootstrapped 95% confidence interval of the indirect effect: -0.31, -0.04). These multimodal findings centrally implicate the AIns in first blunting appetitive impulses in the NAcc, but then also modulating inhibitory control in the VLPFC, and furthermore bridge competing neural circuits to describe how individuals control impulses to obtain incentives.

1-E-14 The Interplay between Prediction Errors, Twitter Mood, and Real-World Gambling

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A growing body of work reveals how unexpected positive outcomes can alter risk attitudes, presumably through changes in moods, resulting in increased risk-taking behavior. Moreover, the effect of these positive outcomes upon mood appears to be nuanced: an outcome exerts a stronger effect when it is unexpected rather than expected, and this manifests in both affective experience and momentary, subjective well-being. Here we examine how real-world unexpected outcomes can shift mood states which are observable at the level of a city, in turn predicting changes in consequential risk-taking behaviour. By analyzing mood language extracted from millions of daily, location-specific Twitter messages, we examine how real-world 'prediction errors' predict day-to-day mood states observable at the level of a city. Studying US six cities over two years, we reveal that day-to-day fluctuations in Twitter-inferred mood states could be predicted by prediction errors stemming from local sports and weather outcomes. These mood states in turn predicted increased per-person lottery gambling rates in a subset of these cities for which we could measure gambling rates, revealing for the first time the real-world interplay between prediction errors, moods, and risk attitudes. Our results demonstrate that fluctuations in mood states underlying real-world risk-taking behavior can be measured through social media.

G – Game Theory & Strategic Interactions

1-G-15 Adjustment dynamics during a strategic estimation task

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Objective: We conduct an experiment to observe adjustment dynamics in a strategic estimation task. To this end, we modify a probability estimation task by including payoffs that are a function of the group's average responses. Subjects attempt to predict the outcome of draws from a Bernoulli distribution that

changes with the group's average responses. First, we test whether individual responses converge toward theoretical equilibria over multiple observations and sessions. Second, we compare adjustment dynamics to those of other coordination games and to those arising from the non-strategic estimation task. Methods: On a computerized program, a group of subjects estimate the hidden probability of drawing a green ring from a box that contains both green and red rings. This hidden probability is a function of the group's current average estimate plus an exogenous constant that changes intermittently. Subjects observe one thousand ring draws per session, with new observations occurring once every 3 seconds. All relevant variables, including the linear mapping function (that relates group responses to the hidden probability) and the response estimate are displayed in graph form with numerical markers during the entire task. In addition, subjects are incentivized to report their true estimate of the hidden probability using a quadratic monetary payoff rule. Results: Average estimates are significantly correlated with the equilibrium solutions implied by the tested mapping functions; in addition, average and individual estimates across time appear delayed as responses converge slowly to observed equilibria. Additionally, we replicate several known patterns of adjustment behavior. Namely, subjects display discrete jumps in their estimates (albeit with an increased frequency of immediate adjustments), a preference for round numbers, and adjustments of both small and large sizes. Conclusions: We combine elements of a coordination game and a probability estimation task to produce a novel paradigm with considerations toward coordination incentives and perceptual evidence. In contrast to previous coordination games, we find an average tendency to converge toward equilibria that are different from theoretical solutions. Compared to results in previous estimation tasks, subjects' estimates of the hidden parameter appear biased (relative to theoretical equilibria as well as momentary best-responses). This confirms prior findings that strategic complementarity results in larger discrepancies between observed collective behavior and equilibrium predictions.

1-G-16 Examining genetic polymorphisms, and the effect of dopaminergic treatment, in Parkinson's patients during an oculomotor mixed-strategy decision-making task

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In mixed-strategy games, player's actions and associated outcomes change dynamically based on their opponent's actions. Such games require choosing among several actions, the likelihood of which is adjusted dynamically based on reinforcement, a process involving frontostriatal networks. The dorsal striatum computes a reward prediction error, and patients with Parkinson's disease (PD) show decreases in prediction error signaling. Further, dopaminergic (DA) treatment alters learning rates in reinforcement learning tasks, potentially contributing to maladaptive decision-making in PD. Variability in response to DA treatment may result from polymorphisms in genes that modulate prefrontal DA transmission (COMT, Val158Met) and striatal receptor density (DRD2 rs6277), and affect reinforcement learning. Using the mixed-strategy game, Matching Pennies, our goals were to: 1) characterize deficits in mixed-strategy decision-making; 2) investigate strategic action selection across multiple motor systems, namely, those controlling the eyes and the hand; 3) examine the effect of DA treatment on choice patterns; and 4) understand the role of genetic polymorphisms in cognitive function, and the effect of DA treatment on cognition, in PD. PD patients (Hoehn & Yahr stage 1-3) and age-matched controls competed in a game of Matching Pennies against a computer opponent that exploited biases in choice patterns. Participants maximized reward by minimizing predictabilities (i.e., choosing stochastically). Choices were indicated with either a saccade or a button press. Both groups completed 2 sessions; patients both on- and off-medication. Finally, we examined the effect of genotype (COMT and DRD2) on behaviour during the strategic game. Patients were impaired in saccade trials, particularly when ON DA medication, evidenced

by lower reward rates, increased spatial bias, increased win-stay, and decreased lose-shift biases, suggesting perseveration in choice patterns. Preliminary genetic analyses show that DRD2 genotype mediated the effect of DA treatment on performance in saccade trials, whereby those with greater D2 receptor density (T/T) showed improved performance OFF medication compared to ON. Although the PD group did not show deficits in button-press trials, COMT genotype mediated the effect of DA treatment on task performance, whereby those with high activity COMT genotype (val/val) showed improved performance OFF medication compared to ON, and the converse was true for those with low activity genotypes (met/met). Understanding the role of genetic polymorphisms in patients' responses to DA medication could lead to individualized treatment to optimize cognitive function.

1-G-17 Neural Correlates of Strategic Interactions: a Single Brain Network Implements the Updating of Both Game and Player Information.

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STUDY'S OBJECT: Most of real life interactions are repeated, rather than isolated, encounters. Such repeated strategic interactions are modeled in game theory (GT) as repeated (or stochastic) games, where the players play a sequence of the same (or different) single-shot game. The theory of repeated games assumes that players choose actions in a game according to strategies. Game theorists have formalized possible strategies for distinct economic games (Finkelstein & Whitley, 1981) and previous experimental studies have identified strategies that humans adopt in different repeated interactions (Fudenberg, Rand, & Dreber, 2012). The aim of this study is to characterize the neurobiological basis of the encoding and processing of critical game variables during strategic playing where either the game or the opponent player (i.e., strategy) may change during the interaction. METHODS: Forty-two participants played a stochastic game while undergoing functional magnetic resonance imaging (fMRI). The game was defined by two parameters: the continuation probability (i.e., the probability of changing the current partner) and the probability of changing the stage game. Thus, during game playing subjects could stay with the same player and game as in the last round or they could change either the player or the game. Participants played with six virtual players (resembling the behavior of real people in analogous situations) two different stage games: the Prisoner's Dilemma (PD) and the Battle of the Sexes (BoS). At the beginning of each trial, information about the opponent player (i.e., one of the six virtual players) and the game to be performed (either PD or BoS) was shown on the screen, followed by a delay in which the participant had to represent all pieces of information and make a choice. Finally, feedback about the choices made by both players was displayed on the screen. The fMRI data from the phase where the information about the player/game was displayed were analyzed. By contrasting trials in which the player (game) changed and trials in which the player (game) remained the same as in the previous round, we aimed to identify brain regions that implement the updating of player (game) information. RESULTS: Preliminary results show that the same brain regions are involved in updating information either about the game or the player. This common network comprises the precuneus, the inferior frontal gyrus, the premotor cortex, and the anterior cingulate cortex. CONCLUSION: These findings suggest that a single brain network implements the updating of both game and strategy information during strategic playing.

1-G-18 A Neuroeconomics Approach to Addressing Common-Pool Resource Problems

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The exploration of what motivates users who collectively make economic contributions to sustainably maintain common-pool resources (CPRs), such as fisheries, forests, and water resources, that encounter free-riders and overexploitation problems is an increasingly thought-provoking research topic. Although field surveys and traditional economics experiments have explored the fact that users' communication and self-governing institutional arrangements enhance their cooperation for economic contribution and thereby resolve CPR problems, studies have not yet explored the neuroeconomics foundation for this phenomenon. We hypothesized that users' economic contributions and their neural activities become interlinked when they communicate and make economic contributions when resolving free-rider problems associated with CPRs. To this end, we conducted a game-theory-oriented neuroeconomics experiment that involved the use of electroencephalographs (EEGs) on 90 participants in a laboratory setting. These participants were divided into 15 groups of six participants each, all of whom had EEG-based neural activity data recorded from different regions of the brain during the experiment in a session. Each session comprised (1) no communication, (2) pre-play face-to-face communication without self-monitoring, and (3) pre-play face-to-face communication with self-monitoring phases. The results indicated that users' economic contributions were (1) higher than zero when they did not communicate in the first phase; (2) high, but not maximal, when they did communicate in the second phase; and (3) sustained, but not increased, when they self-monitored each other's names and contributions in the third phase. Neural activity in temporal lobes that are typically indicative of emotional processing was much stronger than that in frontal lobes, in which rational thought is predominant. Surprisingly, frontal lobe activity did not statistically vary between the no communication, communication, and self-monitoring conditions. On the other hand, neural activity in the temporal lobes generally did. This implies that the level of rationality remained similar throughout all the phases, whereas emotionality tended to be higher as the participants progressed through the no communication, communication, and self-monitoring phases. Based on these results, we suggest that motivational drive created by the interaction of rationality and emotions, as well as its impact on the economic contribution, be assimilated into economic theory and modeling. This implies that behavioral and institutional economics be incorporated into neoclassical economics to increase our accuracy in addressing economic theory and its associated questions.

H – Individual & Lifespan Differences

1-H-19 Episodic memory ability predicts temporal discounting in older adults

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Objective: In intertemporal choice, people prefer rewards sooner rather than later (temporal discounting). Temporal discounting decreases from childhood through adulthood, but research in older adults is inconsistent. This suggests that individual differences in cognitive decline might underlie differences in discounting in this group. One neural system that deteriorates with aging is the episodic memory system, including medial temporal lobe and associated regions. Neuroimaging studies suggest that the episodic memory system plays an important role in promoting patient intertemporal choice. Episodic memory enables people to retrieve detailed memories and to imagine the future. Both of these processes reduce temporal discounting in young adults. Here we examine 1) whether episodic memory ability and temporal discounting are correlated in older adults, and 2) whether we can manipulate discounting in older adults by cueing episodic memory retrieval. Methods: On Day 1, older adults (N=35, ages 65-90) were cued to verbally describe positive memories. One week later, they did an intertemporal choice task with two block types: in Memory blocks, subjects recalled memories they talked about on Day 1 before making a series of intertemporal choices. In Control blocks, they relaxed and attended to

their current state before making choices. We fit hyperbolic discount rates separately in Memory and Control blocks. We also collected intertemporal choice data from additional participants (yielding N=62) to test for a correlation between episodic memory ability and temporal discounting rate. Results: Better episodic memory ability (Word List Memory) predicted lower temporal discounting (r=-0.32; p=0.01). Age (r=-0.12; p=0.37) and executive function (Trails-B test; r=0.09; p=0.51) were not related to discounting, and episodic memory predicted discounting after controlling for these variables (p=0.02). However, positive memory recall did not reduce temporal discounting in older adults as it does in young adults (t(34)=-0.65; p=0.52). Nevertheless, when controlling for trait optimism, there was a significant effect of episodic memory cues on discounting (F(1,33)=7.51; p=0.01) and the effect size was significantly correlated with optimism (r=0.42; p=0.01). Conclusion: We find that individual differences in episodic memory ability are associated with differences in temporal discounting in older adults. Whether positive memory recall reduces discounting in adults, however, depends on their level of optimism. We propose that discounting may be related to episodic memory, but that the influence of episodic recall on subsequent intertemporal choices depends critically on inducing positive affect toward the future, rather than simply engaging episodic memory processes.

1-H-20 Individual Differences in Loss Aversion and Preferences for Skewed Risks Across Adulthood

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In a previous study, we identified age differences in skew preferences and frontal cortical brain activity during skewed risk taking. In the present study, we sought to examine whether individual differences in loss aversion explained the previously observed age differences in skew preferences. 508 healthy participants (ages 21-82) completed self-report and behavioral measures to assess loss aversion and a behavioral measure to assess skew preferences. The behavioral assessment of loss aversion required participants to choose from two gambles each with three equally possible outcomes that differed in the magnitude of the gain. Loss aversion scores were computed from choice data as the ratio of loss aversion to gain seeking. For the self-report measure of loss aversion, participants rated their relative sensitivity to losses versus gains in financial situations using a 5-point scale. To determine skew preference, participants chose to accept or reject either a negative-skew (75% chance of a loss), positive-skew (75% chance of a gain), or a symmetric (50/50 loss/gain) risky gamble. Age was not correlated with behavioral, r = .02, p = .646, or self-report, r = -.04, p = .329, measures of loss aversion. Replicating the previous neuroimaging study, age was positively correlated with positive skew preferences, r =.10, p =.026, such that older individuals were more likely to accept positively skewed gambles. Age was uncorrelated with negative skew preferences, r =.06, p=.182. Behavioral and self-report measures of loss aversion were correlated, r=.123, p = .005. Both self-reported loss aversion, r = -.13, p=.002, and behavioral loss aversion scores, r=-.25, p = .001, were correlated with positive skew-preference, such that individuals with higher loss aversion scores were less likely to accept positively-skewed gambles. This association did not change when controlling for age; both age and loss aversion independently predicted positive skew preferences. There was no significant correlation between either behavioral, r= -.07, p= .1, or self-reported loss aversion, r= -.04, p= .37, and negative-skew preference. In exploratory analyses, loss aversion was more strongly related to positive skew preferences as age increased (age by loss aversion interaction). However, the main effect of age remained significant. Many studies have examined the influence of loss aversion on risk taking but none of which we are aware have examined how loss aversion affects skew preference in any age group. The present findings suggest that age differences in skew preference may be partially but not completely due to individual differences in loss aversion.

Future studies are needed to more directly assess how the valence of decision options affects skew preference across adulthood.

I – Intertemporal Decision-Making & Self-Control

1-I-21 Time preferences are reliable across time-horizons and verbal vs. experiential tasks

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Individual's intertemporal preferences between larger delayed rewards and smaller immediate rewards in the lab are viewed to be predictive of important life outcomes. Moreover, a strong preference for immediate rewards (so-called "impulsivity") is often linked with anti-social behaviors like drug abuse and gambling addiction. For these reasons, intertemporal choice in both humans and animals is widely studied by economists, psychologists and neuroscientists. However, there is a large gap between the methods used to study intertemporal choice in animals and those used in humans. In animal studies, the subject is usually given a large reward on the left and a small reward on the right, and after each time the subject chooses the large reward, the delay for that reward increases a small amount. At some point, the subject will switch to the small reward. This point is taken as a measure of the subject's rate at which they discount delayed rewards or "discount factor". Because animals are required to wait for the reward, the delays are generally less than one minute. In human studies, intertemporal preferences are often measured by asking questions like "Would you rather have $10 today or $15 in one month?". By asking many questions of this type, each subject's discount factor can be estimated. Thus, there are two substantial gaps between animal and human methods of estimating discount factors: short vs. long times and nonverbal or "experiential" vs. verbal choice description. We aimed to bridge the gap between human and animal temporal discounting research by measuring the discount factors of human subjects in three ways. First, we used a novel language-free task for humans that is identical to a task that we also use to train rodent subjects. Second, we tested subjects using a verbal task, but using the same short (< 2 minutes) time scales as in the non-verbal task. Finally, we tested subjects using the standard verbal task with time-scales spanning days to months. This design allowed us to test whether a single process was used for intertemporal choice regardless of time-horizons or verbal vs. experiential situations, or whether the choices in different settings would be better explained by distinct underlying mechanisms. We found that the rank of the subject's impulsivity across the three measures was relatively consistent, with the rank correlation between non-verbal and short-verbal and between short-verbal and long-verbal settings to be around 75% of the correlation that would be expected if subjects used a single discount factor for all three settings. This novel within-subject design validates the use of non-verbal tasks to study the neural mechanisms of intertemporal choice across humans and animals.

1-I-22 Heuristic models outperform traditional utility discounting models across multiple discounting and reward domains.

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Heuristics models have recently been shown to outperform traditional utility discounting models for intertemporal choice tasks. To evaluate domain generality, we examined how well the Intertemporal Choice Heuristics Model (ITCH) predicted choice behavior on a temporal discounting task, but also on physical effort and probability discounting tasks. The time, effort, and probability discounting tasks also included three different reward conditions: social, health, and monetary. We conducted an out-of-sample, cross-validation comparison of the ITCH model and three standard utility discounting models (exponential, hyperbolic, and quasi-hyperbolic) for each task (i.e. time discounting-monetary rewards, time-social, time-health, effort-monetary, etc.). The initial analyses were conducted on the choice

behavior of fifty-nine healthy, adult participants, aged 21-81 (mean 45.63, SD = 17.12, 62% female) who were part of a larger multimodal neuroimaging study. On each trial in each task, participants made a forced choice between a smaller reward available sooner (or with lower effort required or higher probability of receiving the reward) and a larger reward available later (or with more effort required or a lower probability of receiving the reward). The cross-validation comparison was achieved by developing an extensible GitHub library for Bayesian analysis of discounting models for arbitrary discount types, reward types, and model architectures. This library allows for flexible setting of priors on model parameters, GPU accelerated MAP and Hamiltonian MCMC fitting, and support for high dimensional models such as deep networks. We found that the ITCH model out-performed the standard utility discounting models across all task conditions suggesting that heuristics models may better account for human choice behavior across a wide variety of decision tasks and reward domains.

1-I-23 Randomness and sensitivity in intertemporal choice

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Objective: The value of monetary payoffs discounted with time is often understood to be a function of discounted utility. Thus far, many specific discount functions have been proposed to account for observed preferences. However, all empirical measures of intertemporal choice show such choices to be probabilistic. This random element has remained largely disparate from theoretical and empirical discussions. Using an extensive 2-AFC paradigm, we simultaneously measure discounting behavior, the sensitivity of choice against decision variables (e.g., of delay and payoffs), and tested for scale-invariant decision thresholds. Methods: Subjects (N = 14) completed 672 choices (across 2 sessions) between an immediate payoff and a payoff at some delay. Immediate offers ranged from $5.50 to $31.40. A fixed series of delayed payoffs was paired with each level of the immediate payoff as alternatives. Possible delays ranged from 25 to 150 days in increments of 25 days. Choices were presented in a randomized order and a single choice from each session was chosen at random as an actualized reward. Results: In a model comparison exercise, hyperbolic, hyperboloid, and exponential discounting best accounted for 8, 4, and 2 subjects respectively. The average indifference value for immediate payoffs increases in a concave manner with delay. This increase is attenuated (i.e., less discounting) with larger immediate offers. Choice sensitivity toward payoffs systematically decrease with increasing duration and increases with the magnitude of the immediate payoff. In terms of scale invariance, a single choice curve well approximates choice probabilities at shorter delays. Conclusions: Choice behavior in this paradigm is consistent with previously documented effects in discounting. Namely, decreased discounting with larger immediate offers (i.e., magnitude effect) and increased discounting with longer delays (i.e., duration effect, as in hyperbolic discounting). However, the rate at which discounting increases with delay is at odds with popular families of discount functions. The choice sensitivity relationships imply an increased coding precision with greater average payoffs, along with a decreased coding precision with increased delay. These patterns suggest a particular deployment of endogenous attention during intertemporal choice. Future work calls for a parsimonious model of behavior that captures the random nature of the choice process as well as apparent preferences.

1-I-24 Self-control in decision making involves prefrontal theta band oscillatory dynamics

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Decisions and choices that require self-control or cognitive control are often associated with increased activity in prefrontal regions, in particular the medial prefrontal cortex (mPFC) and lateral PFC (lPFC). Functional magnetic neuroimaging studies of dietary choice have found that the mPFC carries subjective

value signals, and these signals were modulated by activity in the lPFC when dieters made healthier choices. In addition, electroencephalography (EEG) studies have shown that mPFC and lPFC activity--specifically theta band oscillatory dynamics--was associated with self-control processes such as monitoring for conflict and signaling the need for increased cognitive control, but mostly during perceptual and sensory-motor decisions. Whether prefrontal theta band oscillations support self-control during value-guided choice remains less clear. Here we investigate whether prefrontal theta band oscillations measured using EEG are associated with self-control during a dietary choice task. Healthy, hungry, and non-dieting participants indicated how much they wanted to eat different foods that varied in tastiness and healthiness, and were occasionally asked to focus their attention on how healthy or tasty each food was. Behaviorally, we found that participants responded more slowly when they did not have strong preferences for a given food. In parallel, this decision conflict was reflected in enhanced midfrontal theta power. Participants made more or less healthy choices when focusing on healthiness or tastiness respectively, and this effect was supported by mPFC and lPFC theta dynamics. These findings suggest that prefrontal theta band oscillatory dynamics, which have usually been associated with action monitoring and cognitive control during inhibitory tasks such as the flanker task, might also underlie successful self-control during value-guided choice.

1-I-25 Is it time? Examining the effects of episodic imagining on reward discounting

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Background: "Mental time-travel" affords us the ability to simulate hypothetical episodes, shaping our decisions about the future, and it is well-established that the brain's medial temporal lobe (MTL) contributes to these processes (Addis, Wong, & Schacter, 2007; Szpunar, 2010). This has been illustrated in studies of intertemporal choice, where providing participants with personally meaningful cues (e.g., "your brother's wedding") prior to making these decisions greatly reduces the discounting of future rewards in healthy adults (Benoit, Gilbert, & Burgess, 2011; Peters & Büchel, 2010) but not in amnesic patients with MTL damage (Kwan et al., 2015). Nevertheless, it is unclear whether these future-oriented decisions are simply influenced by episodic thinking that taps into the role of the MTL via specific, personally relevant cues. Could it be that imagining personal cues is sufficient to make decisions, and not the active engagement of temporal processes? If so, a question that emerges is whether episodic imagining provides the same modulatory effect in other forms of decision-making that do not have a temporal component. Methods: 32 young adult participants completed an intertemporal choice task with and without cues to imagine personally meaningful future events, as well as a non-temporal probabilistic discounting task, where they selected between smaller, "guaranteed" rewards and larger, less certain rewards with and without personal event cues. Results: As previously demonstrated, participants showed a reduction of future discounting in their reward choices on the intertemporal choice task when provided with personal event cues. By contrast, compared to a baseline task of standard probabilistic discounting, the provision of personal event cues did not affect decisions on the probabilistic discounting task. Conclusion: Personally meaningful event cues may have a selective influence on discounting behaviour that is future-oriented, possibly through an interaction with the temporality of delayed rewards; discounting of probabilistic rewards does not appear to show the same sensitivity to personal event cues. These findings may further delineate the role of the MTL in choosing between rewards when future-oriented decisions are concerned.

1-I-26 Constructed intertemporal preferences are greater than their revealed counterparts

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Objective: Intertemporal choices are common in everyday decisions. In the neuroeconomics domain, these decisions involve relative preferences and tradeoffs between monetary outcomes that occur at different temporal delays. Research from the past two decades characterizing the psychology of intertemporal choice has largely been conducted under the framework of revealed preference. Studies involving intertemporal choice under the tenets of constructed preference has only covered a subset of conditions of interest, such as asking participants to provide an amount for a future outcome relative to an immediate outcome. In this study, we seek to study the full set of conditions for intertemporal choices under the constructed preference framework. Methods: Participants (N = 63, mean age ± std = 24 ± 4 years) were asked to construct their preferences for an accelerated outcome or for a delayed outcome by providing a response for either a dollar amount or a temporal delay (in days) for the smaller, sooner or for the larger, later options, respectively. Participants also completed a classic intertemporal choice task, choosing between smaller, sooner and larger, later options. We recorded eye tracking data using a Tobii T60 eye tracker. Results: We found that participants were steeper discounters for constructed (mean log(k) = -4.28) compared to revealed preferences (M = -3.17, $p<0.001$). Constructed intertemporal preferences were steeper when participants provided a temporal delay response (M = -3.69) compared to an amount response (M = -2.63, $p<0.001$). Using eye tracking and drift diffusion modeling, we also found that such preference reversals occur in tandem with differential processing and weighting of amount and time attributes across procedures. Using the Payne Index as a proxy of processing strategy, we found the following differences. Under revealed preference, participants relied more on an attribute-based strategy (M = -0.18), shifting gazes between options within a single attribute. Under constructed preference, participants relied on an attribute-based strategy (M = -0.11) when providing a temporal delay response but an alternative-based strategy, shifting gazes within an option between attributes, when providing an amount response (M = 0.04). Conclusions: Results from this study suggest that intertemporal preference is susceptible to the procedure used to measure it, harking back to classic studies on risky choice and violations of procedural invariance. Additionally, implications from this study suggest an alternative perspective to using intertemporal choice as a marker of impulsivity: we should consider the state versus trait characteristics of intertemporal preference as a proxy for impulsivity.

J – Learning & Memory

1-J-27 Choice reactivation is a mechanism for contingent learning

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Introduction In order to make sound economic decisions, animals must appropriately attribute rewarding and aversive outcomes to their most likely causes. How the brain achieves this feat from amongst the vast array of possible causes remains poorly understood. Recent work has shown that BOLD activity in the lateral orbital frontal cortex (lOFC) responds to contingent but not non-contingent rewards and reflects identity prediction errors (PEs) used to update stimulus-outcome associations. Despite the insights gained from mapping such learning computations, little is known about how they drive learning. One putative mechanism for contingent learning uses a memory trace of the causally relevant choice at outcome time to drive plasticity between representations of the rewarding event and its likely cause. Methods We designed a task that encouraged participants to select their desired gift card outcome and then reverse-infer which stimulus to choose to obtain it. In condition1 (signaled at the onset of the block), choices were resolved after a variable delay. In condition2 they were only resolved after a second choice had been made. This manipulation ensured that the relevant causal choice was not always the

most recent choice made. We performed multivoxel pattern analyses (MVPA) and model-based fMRI analyses to test for a representation of the causal choice at feedback time and its dependence on PEs produced during learning. Results Behaviorally, multiple logistic regression analysis revealed that subjects were able to appropriately attribute the current outcome to the most recent choice in condition1($t(19)=9.07;p<0.0001$) and to the previous choice in condition2($t(19)=3.18;p=0.0025$), motivating attempts to identify a neural representation of the causal choice at feedback in both conditions. Using a whole-brain search light procedure, we found the relevant causal choice could be decoded from lateral inferior occipitotemporal cortex, lateral prefrontal cortex, and lOFC in both condition1($t(19)>3.58;p<0.001$ uncorrected) and, although less robust, also in condition2($t(19)>3.1;p<0.005$ uncorrected). Finally, we reasoned this causal choice representation may sharpen in brain areas important for updating associations precisely when they should be updated most. Consistent with this prediction, trial-by-trial classification probabilities of the causal choice at feedback were predicted by the trial-by-trial identity PE (KL Divergence), in lOFC alone($t(19)>5.0$, $p<0.0001$ uncorrected). Conclusions Collectively our findings suggest the recoding of past choices in this network is a mechanism for identity PEs to update the causally relevant stimulus-outcome association for goal-directed choice.

1-J-28 Memory beliefs explain why decisions are biased by memory

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Objective: Many preferential choices necessitate retrieving relevant information from memory. Previous work showed that people prefer remembered over forgotten options even when the forgotten options are more likely to be better. In the present, pre-registered study, we tested a mechanistic explanation for the existence of this memory bias: People may believe that they remember options of high value better than options of low value and may thus discount values of forgotten options. Methods: We tested n = 64 participants in a three-stage behavioral experiment. In the first part, participants evaluated a set of food snacks with respect to how much they would like to eat each snack at the end of the study. In the second part, they chose between snacks but had to retrieve the snacks' identities from memory (i.e., snacks were first linked to locations on the screen; during choice, only the locations were presented, and snack identities had to be recalled). In the last part, participants indicated how often they think they had successfully remembered each snack during the second part of the experiment. Logistic and linear regressions were used to quantify the influence of memory on decision making (i.e., the memory bias) and the value-dependency of memory belief, respectively. The main hypothesis was that the coefficients resulting from these regressions would be positively correlated with each other across participants. Results: First of all, we replicated the effect that choices are biased by memory: When choosing between a forgotten and a remembered option, participants had a clear preference for the latter, even when correcting for value and true memory performance ($t(63) = 5.88$; $p < .001$). As predicted, we also found that participants believed to remember better options better, even when correcting for true memory performance ($t(63) = 4.52$; $p < .001$). Third, we confirmed our central hypothesis that the memory bias on choice is correlated with the value-dependency of memory belief ($r = .36$; $p = .002$). In other words, participants who strongly believed to remember good options more often than bad options also exhibited a stronger influence of memory on value-based decisions. Discussion: Our study provides one mechanistic account for the biasing influence of memory on decision making. People believe to retrieve higher-valued options more often, and forgotten options are discounted for the very reason that they are forgotten. Importantly, these findings characterize the memory bias on choice as a (partially) rational

choice strategy: If a decision agent believes to remember good options more often, it is adaptive (within the context of this belief) to assign remembered options a higher value.

1-J-29 Overlapping error signals for value- and identity-based state transitions in the human midbrain

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Objective: Midbrain dopamine activity has become almost synonymous with prediction errors for reward value. These error signals are thought to update associations between predictive events and the value of outcomes, and are a key ingredient of many computational learning algorithms. However, the learning that is supported by these value error signals is relatively simplistic and does not account for the complexity of real-world associative structures that are required for model-based control of behavior. Here we test the idea that midbrain responses are capable of signaling other types of errors and thereby support much richer forms of learning. Methods: We used a reversal learning task in which hungry participants chose between two visual conditioned stimuli (CS) to receive either high- or low-intensity (i.e., value) versions of sweet or savory food odors during high-resolution functional magnetic resonance imaging (fMRI). At regular but unpredictable intervals throughout the task, either the value (but not the identity) or the identity (but not the value) of the predicted odor outcomes was changed, signaling an identity- or value-based transition into a new task state. Results: Participants (N=23) reliably chose to smell high-intensity odors, and switched their choices accordingly when the value associations changed. These choices were well explained by a reinforcement learning (RL) model. Most importantly, estimates of prediction errors derived from the RL model related to reward identity and reward value were both correlated with fMRI activity in the midbrain. Moreover, using multivoxel pattern analysis, we found that task states differing only in the identity of the outcomes associated with the CS, could be decoded from activity in the OFC. Conversely, task states differing only in which CS was associated with the high and low value of the outcome, could be decoded from activity in the amygdala. Conclusions: These findings demonstrate that value- and identity-based features of task states are encoded in different brain areas. However, transitions between these states are driven by prediction errors for value and identity arising from a common midbrain origin. This suggest that prediction errors for value are only one example of a more general error signaling mechanism that is capable of supporting the learning of complex associative structures required for model-based behavior.

K - Methods

1-K-31 A large-scale analysis of test-retest reliabilities of self-regulation measures

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O-Measures of self-regulation come in many forms including both cognitive tasks (CT) and surveys (S). Researchers often assess their relationship with real-world behaviors (e.g. unhealthy eating, drug abuse), implicitly treating them trait-like/stable across time. Test-retest reliability is a prerequisite for S but rarely established for CT. To establish this especially for CT measures we administered a large behavioral battery twice and evaluated reliabilities of both traditional and exploratory dependent variables (DV). M-150 MTurk subjects completed a10-hr battery of 63 tests (26 Ss, 37 CTs) twice (average delay=115 days, range: 60-228 days). In addition to standard DVs we fit drift diffusion models (DDM) whenever possible, yielding 344 measures (70 S, 274 CT DVs). Measure of reliability was intraclass correlations (ICC). R- S measures were significantly more reliable than those of CT (t(342)=-12.6,p<.001;S ICC's range: 0.50-0.95, median=0.88; CT range: -0.38-0.88, median = 0.53). We summarized multiple measures for

tasks in two ways. 1.We looked at the median ICC's of all the measures for each CT. Top five tasks: adaptive n-back (0.84), two delay discounting (DD) measures (0.82-0.80), Stroop (0.77) and recent probes (0.77). The bottom five: probabilistic selection (0), two-stage decision-making (0.04), a five-item DD (0.27), dietary decision-making (0.40) and the angling risk task (0.41). These task-level summaries were independent of the number of trials ($t(33)=0.37, p=0.71$) but were negatively correlated with the number of variables included ($t(33)=-2.1$, $p=0.04$). 2.We compared the ICC's for variables associated with 20 putative cognitive processes (e.g. delay discounting, working memory). Delay discounting, response speed, response selection, working memory, selective attention had higher reliabilities (0.66-0.80); resisting proactive interference, cue encoding, alerting, proactive and reactive control had lower reliabilities (0.08-0.18). We also compared raw response time (RT) and accuracies (A) to DDM parameters. Both model parameters and raw measures were more reliable when using all trials instead of difference scores ($t(204)=15$, $p<0.001$). For these overall estimates drift rates had significantly higher reliabilities compared to raw A ($t(38)=2.17$, $p=0.04$) and were no worse than raw RT ($t(41)=-0.65$, $p=0.52$) but this was not true for other parameters (threshold, non-decision time). C-We confirmed high reliability of S measures on MTurk, whereas there was a broad range of reliabilities for CTs. This highlights the importance of psychometric characterization for CT measures before they are used as individual difference (ID) variables. Some DDM parameters were more reliable than raw behavior, thus they may provide new insights in ID analyses.

1-K-32 Toward a proof of concept for neuroimaging-based financial-system regulation: Near-infrared spectroscopy (NIRS)-recorded lateral neocortical activity in lab markets with monotonically decreasing or peaked fundamental values

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Objective: To build an experimental design that could yield a proof of concept for neuroimaging-based financial-system regulation, the present review aims to: 1) find evidence that near-infrared spectroscopy (NIRS) could detect low lateral neocortical activity as an asset-price bubble biomarker and 2) seek a lab-market paradigm that could model the uncertainty that financial-system regulators have about whether rising asset prices represent a bubble. Methods: A systematic literature review focused on NIRS and lab-market studies to develop the above experimental design. Results: NIRS-recorded prefrontal cortical activity was higher in the "cold" deliberative version of the Columbia Card Task (CCT) compared to the "hot" affective CCT version (Holper & Murphy, 2014). These results suggest the use of NIRS to detect low lateral neocortical activity as a bubble biomarker, consistent with the hypothesis that evolutionarily ancient or new neurocircuitry, respectively, drives decision making during bubble or non-bubble periods of financial market activity (Haracz, 2013). A proof of concept for using this biomarker in a financial-system regulatory setting would be enabled by designing a lab-market paradigm that reliably generates asset-price increases during either bubble or non-bubble market periods, thereby modeling the above regulators' uncertainty. Two versions of a well-studied continuous double auction paradigm (Smith et al., 1988) could be used: assets in standard (S) lab markets would have a monotonically decreasing fundamental value that typically yields price bubbles (Smith et al., 1988), whereas assets in peaked (P) markets would have a fundamental value that peaks (i.e., rises in early periods of asset trading and falls in later periods [Noussair & Powell, 2010]). In P markets, asset prices tend to closely track fundamental value, so no bubble is yielded typically. This tendency could be strengthened by adjusting subjects' cash and asset endowments. Price peaks represent a bubble in S markets, but not in P markets. A subject acting as a regulator could observe computer-displayed NIRS-recorded lateral neocortical activity from asset-trading subjects along with ongoing asset prices and trades, but the omission of fundamental

values would blind the regulator to whether markets are S or P. Therefore, the regulator would be trained to use NIRS data (i.e., low lateral neocortical activity) to detect bubbles and implement asset-holding caps (Lugovskyy et al., 2014) to deflate bubbles, thereby yielding a proof of concept for neuroimaging-based financial system regulation. Conclusion: NIRS and lab market studies could yield the above proof of concept.

L - Risk & Uncertainty

1-L-33 Eye movements as a readout of implicit spatial prediction

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Introduction: Human decision-makers must often update their beliefs in response to new observations. The degree to which beliefs should be updated is highly dependent on context: In stable but noisy environments, new observations should be given limited weight, while volatile environments require more rapid updating. We probed the dynamic adaptation of belief update (or learning rate) using eye tracking in a free-viewing spatial prediction task. By using oculomotor behavior as a readout of the subjective predictive distribution, we have access to a continuous, implicit, and multidimensional set of predictions. Methods: Participants (N=14) were asked to make odd/even judgments about briefly presented numerical digits while their eye movements were recorded. Because the digits appeared in variable spatial locations and were presented briefly with crowding and backward masking, participants were implicitly required to predict the location of the next number in order to use central vision to successfully perform the task. Four types of experimental blocks were used to parametrically vary the predictability of successive spatial locations. Analyses focused on anticipatory eye movements during the blank interval that preceded each trial. Results: First, we replicated prior results from experiments that elicited discrete, explicit predictions. We found that eye position just prior to the digit's appearance reflected multiple influences on belief updating, including change-point probability and estimation uncertainty. As expected, these predictions showed a greater influence of the most recent observation in conditions with the least uncertainty, whereas greater uncertainty was associated with predictions that pooled over a larger number of previous observations. Additionally, the variability of gaze position increased with uncertainty level in anticipation of the digit appearance, indicating that the internal predictive distribution is indeed observable in anticipatory eye movements. Though we initially hypothesized that gaze would stabilize towards the end of the anticipation interval, gaze position was in fact significantly more variable in the latter half of the interval ($p < 0.05$). This effect weakened with increasing uncertainty. Conclusions: These results suggest that oculomotor behavior can serve as an informative readout of internal belief states, and provide insight into the construction and update of predictive distributions with fine temporal precision. Importantly, this free-viewing spatial prediction paradigm allows us to measure a dynamic manifestation of subjective uncertainty, which was inaccessible through prior approaches.

1-L-34 Variance Aversion in Decisions Under Uncertainty

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We propose that variance, defined as the level of dispersion between monetary payoffs, is a measure that can predict choices in risky and ambiguous lotteries. Variance is a function of the distance between monetary payoffs in ambiguous lotteries while it is a function of both probability weighting and payoff distance in risky lotteries. Given the amount of information that subjects have to process to make a decision, we also show that behavioural measures such as response times are also predictive in determining the choices subjects make. In three behavioural experiments, we demonstrate how variance

and the decision processes involved to determine it, can fully explain many aspects of decisions under uncertainty.

1-L-35 Do you trade stocks? Understanding the drivers of real-life financial risk taking

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Objective: It is still a puzzle why half of households in Europe and the US do not participate in the stock market, despite the positive long-run effects of investing on wealth accumulation. Psychologists have investigated financial risk taking, mainly by using lab-based experiments. Economists have studied real-life stock ownership using household characteristics, personality, as well as subjective and objective measures of financial risk taking. In this study, we combine an extensive set of cognitive and non-cognitive skill measures, rich data on socio-demographic characteristics, as well as brain activation from a functional magnetic resonance imaging (fMRI) stock learning paradigm to explain real-life stock trading behavior. Methods: In a non-convenience sample of 198 working-age males (39.0 ±6.7 years), we used Principle Component Analysis (PCA) to identify two important categories of factors driving active stock trading (?Do you trade stocks yourself??), which we termed risk tolerance and risk optimism. We then used the household characteristics and risk indices to perform logistic regression analysis and model comparison including Receiver Operating Characteristic (ROC) curves. Next, we extracted weighted beta estimates from predefined regions of interests (ventral striatum, anterior insula (AI), ventromedial prefrontal cortex) taken from the neuroeconomics literature (Smith et al. 2014, Preuschoff et al. 2008, and Bartra et al. 2013) and included these variables as part of a more comprehensive model explaining active stock trading. This was then followed by mediation analysis. Results: We find that the model including risk tolerance, risk optimism, and household characteristics, can correctly classify individuals as active stock traders in 82% of the cases. Next, using fMRI data from a large sample (n=157), we show that activation in the AI during risky (stock) versus riskless (bond) choice is associated with active stock trading in real-life and that this association is mediated through risk tolerance and risk optimism. Conclusions: To our knowledge, we provide the first comprehensive model that builds on psychological and economic insights to explain sources of heterogeneity observed in real-life financial risk taking. Additionally, we provide evidence for the association between risk-related brain activation and real-life financial risk taking. Acknowledgements: This study was partly funded by the Frankfurt Institute of Risk Management and Regulation.

1-L-36 Ambiguity aversion, but not risk aversion, is associated with cumulative lifetime stress exposure

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Objective: Although the effects of acute stress exposure on decisions about uncertainty are equivocal across the literature, emerging research suggests that exposure to stress across the lifespan may play a more instrumental role in shaping these preferences. Research examining the effects of stress on economic decisions have primarily focused on choices for which outcome probabilities are explicitly known (i.e., risk). However, decisions are often made when the probabilities of different outcomes are unknown (i.e., ambiguity). Here, we used a standard experimental economic paradigm that dissociates attitudes toward risk and ambiguity to assess how lifetime stress exposure affects economic decisions regarding uncertainty. Method: Fifty-eight healthy individuals completed a decision-making task in which choices are made between an uncertain lottery and a certain gain. Self-reported state anxiety levels were collected using the State-Trait Anxiety Inventory before the choice task, and lifetime stress exposure levels were measured afterwards using the Stress and Adversity Inventory (STRAIN), a detailed interview

assessing major stressors occurring over the life course, which, unique among stress inventories, accounts for stressor frequency, severity, duration, and recency in a quantitative manner. Results: Neither state anxiety nor lifetime stress were related to individuals' risk attitudes, captured by the proportion of lotteries selected during the choice task, for risky lotteries where outcome probabilities were known. However, the STRAIN data--specifically, the total number and cumulative severity of lifetime stressors--revealed a significant negative correlation with the proportion of ambiguous lotteries selected, indicating that higher levels of lifetime stress exposure were related to a lower willingness to accept ambiguous lottery offers. Model-based estimates of risk and ambiguity attitudes mirror these results--Spearman correlations were significant between lifetime stress exposure and the ambiguity attitude parameter but not the risk attitude parameter. A similar association emerged between state anxiety and the proportion of accepted ambiguous lotteries. Conclusions: These findings suggest that lifetime stress exposure accounts for the lion's share of individuals' tolerance for situations with ambiguous reward probabilities, but has little effect when the outcome probabilities are precisely known. Since most decision-making falls into the former category, this has implications for healthy and chronically stressed populations alike and their economic behavior in a broad range of ambiguous contexts (e.g., retirement investing, real estate).

1-L-37 Information Sampling in Trust Decisions

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People often have only limited information when deciding whether or not to trust another. Sometimes however, the decision-maker can gather information about a trustee's past behavior before making a trust decision. Then, it is optimal to gather more information when the trustee's trustworthiness is less certain, and also when information acquisition is less costly. Here, we examine the effect of these two factors on information sampling in a Trust Game. Additionally, we examine the effect of social context, namely whether the potential trustee knows about the information sampling. We find that players seek more information when sampling is cheap and when previous samples are less conclusive. Moreover, when sampling is cheap, social context also has an effect; Subjects sample less when the potential trustee knows about the information sampling. Our data are quantitatively accounted for by a Markov model in which the decision-maker maintains a posterior distribution over trustworthiness and maximizes reward expected under that distribution. Our study opens the door to broader applications of the tools and models of information sampling to social decision-making.

1-L-38 Transcranial magnetic stimulation of the right DLPFC modulates both risk aversion and probability weighting

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Objectives: Recent economic theories of choice under risk postulate that the observed risk-taking behavior in monetary domain may be a result of the value of money (i.e. how much a person values one additional dollar, or decreasing marginal utility of money) as well as specific perception of probabilities (i.e. probability weighting). However, existing neuroeconomic studies of risk taking usually focus on the analysis of the degree of the observed risk taking per se without disentangling its individual components. Employing Transcranial Magnetic Stimulation (TMS), we attempt to disentangle the effects of decreased dorsolateral prefrontal cortex (DLPFC) excitability on the marginal utility of money and on the perception of probability in risky choice. Methods: In the present study, a within-subject design is employed. Participants attend the laboratory for the two sessions separated in time by 6 or 7 days strict. In each session, they first undergo a 40-second repetitive TMS by a perturbation continuous theta-burst (cTBS)

protocol on either the right DLPFC or the vertex as a control site in a randomized order. After the stimulation, participants answer a series of 96 binary lottery choice questions presented in a randomized order in the domain of gains as well as losses. There questions comprise several Multiple Price Lists similar to a well-known Holt and Laury (2002) task widely used in Economics and Neuroeconomics to estimate the parameters of risk preferences. A rich set of data on each participant allows us to estimate not only the coefficient of risk-aversion, but also the parameters of probability weighting by fitting the rank-dependent utility model with Prelec two-parametric probability-weighting function. Results: Results of a pilot experiment suggest that, in the gain domain, down-regulation of the right DLPFC excitability tends to make participants more likely to risk (relative to vertex stimulation). At the same time, participants become significantly more pessimistic with respect to the probability of the best lottery outcome. This pattern is reversed in the loss domain: participants tend to become less likely to risk, while being significantly more optimistic with respect to the probability of the worst outcome. Thus, our results suggest that the right DLPFC mediates risk-taking behavior via an involvement in probability weighting.

1-L-39 Integrating Decision Theory with Neuroscience to Predict Risk Taking: Neural Correlates of Self-Reported Criminal Behavior

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Criminal behavior has been associated with abnormal neural activity when people experience risks and rewards or exercise inhibition. However, neural substrates of mental representations that underlie criminal and noncriminal risk-taking in adulthood have received scant attention. We take a new approach, applying fuzzy-trace theory, to examine neural substrates of risk preferences and criminality. According to fuzzy-trace theory, adults rely mainly on gist (bottom-line meaning), which produces developmental increases in decision biases such as framing effects (preferring sure gains and risky losses). In contrast, adolescents are more likely than adults to rely on "verbatim" (literal and precise) representations that support trading off degrees of risk and reward, the latter promoting unhealthy risk-taking. We extend predictions about gist and verbatim representations that explain adolescent risk-taking to uncover neural correlates of developmentally inappropriate adult risk-taking. As predicted, risk-taking was correlated with risk preferences called "reverse framing" (preferring sure losses and risky gains, reversing typical framing biases) linked to risky behavior in adolescents and rarely observed in nondisordered adults. Experiments confirmed processing interpretations based on fuzzy-trace theory and rule out prospect-theory explanations. Furthermore, brain covariation with risk-taking was observed predominantly for reverse-framing choices. Noncriminal risk-taking behavior covaried with emotional reactivity (amygdala) and reward motivation (striatal) areas, whereas criminal behavior covaried with greater activation in temporal and parietal cortices, their junction, and insula. When developmentally typical framing choices were made, reflecting non-preferred gist processing, activation in dorsolateral prefrontal cortex covaried with criminal risk-taking, which may reflect cognitive effort to process gist while inhibiting preferred verbatim processing.

M - Social Rewards & Social Preferences

1-M-40 Stimulating the right posterior superior temporal sulcus modulates the formation of negative ties during economic exchanges

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Building and maintaining cooperation with other individuals requires that our brain keeps track of long term outcomes of previous interpersonal interactions. We developed a social ties model which assumes

that individuals build a tie with their partners, which in turn determines their own level of cooperation. The tie is updated after each interaction and therefore constitutes an integrated signal of the quality of past interactions with a specific person. Previous research showed that social ties are encoded in the right pSTS and TPJ. Moreover, functional connectivity between the pSTS and mPFC mediated the effect of social ties on choice behavior. The goal of this study was to investigate whether these regions have a causal role in mediating the effect of positive and negative social ties in cooperative and competitive behaviors. We hypothesized that increasing the excitability of that region will result in stronger ties. Participants received anodal and sham stimulation over the right pSTS/TPJ area in two distinct sessions with a three weeks interval. During each session, participants interacted in a two-person fragile public good game with two different other players sequentially. In this game, participants can either cooperate by investing money in a common account which results in the partner winning more; or compete by destroying money from the common account which results in the partner winning less and thus the participant winning more than the partner. Unknown to the participant, the other players' behavior was simulated using two reciprocity-based (tit-for-tat) algorithms. One algorithm, the kind player was pushing towards cooperation with a sudden brake of cooperation in the middle of the game. The other algorithm, the nasty player is mostly driving the interaction towards taking money from the common account. We estimated the social ties model, and tested the effect of tDCS stimulation of two parameters of the model, (1) the tie persistence, a measure individuals' propensity to maintain tie in the long term, and (2) the tie proneness which measure the immediate impact of others' behavior on current decisions. As hypothesized, anodal stimulation on the pSTS/TPJ region significant increased the ties persistence, i.e. how the interaction history influenced present choices, although only when interacting with the nasty player. However stimulation did not change participants' ability to react impulsively to others' behavior. To conclude, increasing the excitability of the pSTS/TPJ facilitated the development of long term negative ties during social decisions. Past unkind behavior of the other person had more impact on current behavior of participants. Immediate responses to unkind behavior were not affected.

1-M-41 Dopaminergic modulation of the functional connectome and its effects on facial attractiveness judgment

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Previous studies have presumed a link between facial attractiveness judgment and the dopaminergic system. However, it is still elusive whether manipulation of the dopaminergic system impacts facial attractiveness judgment. In a within-subject design, we combine pharmacological intervention and functional magnetic resonance imaging to investigate how dopamine changes the connectome of resting-state networks and subsequent attractiveness judgment in 28 female subjects. We hypothesized that pramipexol, a dopamine agonist, modulates both attractiveness judgment and resting-state functional connectivity (RSFC), and that these neural-behavioral modulations will be related. Our results show that acute oral administration of dopamine leads to enhancement of attractiveness judgment independent of attractiveness levels. Further, dopamine-dependent changes in whole-brain RSFC predicted individual differences in attractiveness judgment increase. Connectivity strength of both the cinguloopercular (CON) and sensorimotor networks were mostly increased by dopamine administration. However, the CON was the only network able to significantly predict participants' attractiveness judgments in the dopamine session. Our results suggest that dopamine affects social judgments via modulation of large-scale brain dynamics.

1-M-42 Habit-like and goal-directed choices reveal different social preferences

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We compare how social preferences (SP) are revealed through habit-like (HB) actions and goal-directed (GD) choices. The role of HB and GD processes in choices over rewards for oneself has been a subject of great interest. But little is known about their role during social choices that involve outcomes for oneself and others. Participants (N=66) made HB or GD choices in a binary-choice charitable giving task. In both conditions, individuals faced the same set of binary choices. For the HB condition, participants learned the payoffs for each cue via feedback over 3 days of online training to establish stable stimulus-response associations. In GD trials, the payoff combinations for self and charity were directly displayed on novel cue images never seen during training or repeated during the task. Participants completed a separate measure of social value orientation (SVO; Murphy et al., 2011). We analyzed the data using a Bayesian hierarchical logistic regression for selfish choice outcomes as a function of condition and SVO at the group level, and sequential sampling models (SSM) fit to each subject by condition. The group-level analysis showed that participants revealed more extreme SP during GD compared to HB choices. Overall, participants maximized self over charity payoffs 75% of the time. However, high SVO individuals made fewer selfish choices (1st quartile = 87%; 4th quartile = 44%). The selfish choice rate was also lower during HB compared to GD trials (beta = -0.31, 95% credible interval (CI) = [-0.52, -0.11]). Moreover, there was an interaction between SVO and condition (beta = 0.26, CI = [0.06, 0.45]) such that selfish individuals became more selfish while prosocial individuals were more charitable on GD than HB trials. Next, we tested if the change in selfish choice rates was related to SSM parameters capturing specific aspects of the choice process. We found that the starting point bias during HB choices (i.e. the tendency be selfish regardless of the payoffs) positively related to the increase in selfish choices on GD trials (beta = 0.17, CI = [0.07, 0.27]). Furthermore, the sensitivity to self-payoffs (i.e. the extent to which decisions depended on payoff amounts) in HB choices was negatively related to the increase in selfish choices on GD trials (beta = -0.10, CI = [-0.18, -0.02]). Lastly, we note that only the response threshold and non-decision time SSM parameters differed between GD and HB trials. GD choices have higher computational costs and time pressure, resulting in a greater influence of payoff-independent selfish or prosocial biases on choices. This leads to more extreme levels of behavior in the GD compared to HB trials. The influence of the bias may be reduced in HB trials because of the long period of preference formation.

1-M-43 Discovering Social Groups via Latent Structure Learning

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Humans form social coalitions in every society, yet little is known about how we learn and represent social group boundaries. Here, we use a novel approach to social group representations through a domain-general, computational model of latent structure learning. We find that it predicts social preferences better than the typical inputs of explicit category labels and similarity (e.g., race and team memberships). Four experiments examine (1) how evidence for group boundaries is accumulated in a consequential social context; (2) how these boundaries drive one's own choices and attributions about other agents; and (3) whether these latent groups affect choice in the presence of group labels contradicting the latent group structure. Across 8 political values (e.g., "Do you support the death penalty?"), subjects state their stances and learn 3 other agents' stances. Two agents, A and B, each agree with the subject on 4 values; a third agent, C, agrees with B on 5 values. Crucially, we manipulate C's agreement level; C agrees with the subject either on 7 values (causing subjects to form latent groups of themselves, B, and C) or on 1 value. When asked whose mystery political stance (A's or B's) they would rather follow, subjects are more likely to choose B only when a latent group is formed through the influence of C. This contradicts traditional models, which predict equal rates of choosing A and B and

that C's presence should not matter. We demonstrate the effect (Experiment 1); find that it persists despite stereotypically inconsistent profiles (e.g., supporting the death penalty and being pro-choice; Experiment 2); leads subjects to rate B as more likeable, competent, and moral regardless of their mystery political stance choice (Experiment 3); and persists in the presence of the explicit, countervailing labels of team memberships. Even when B is always an opposing team-member and A is always a fellow team-member (leading to the possibility that subjects will always choose A), the effect still holds (Experiment 4). Social groups drive a vast array of decisions, from the most quotidian (who do I approach at this party?) to the most consequential (who do we target with missile strikes?). Traditional models assume that we form groups based on explicit labels and similarity to oneself. Instead, we show that agents' relations to one another as well as to the subject better explain social influence and behavior. These latent groups affect decisions about whom to trust with making the best social decisions. Understanding how we infer such groups and the flexibility of these inferences is a crucial first step to identifying how to diminish intergroup bias.

1-M-44 The influence of gaze direction on willingness to pay: Eye can tell you what to buy

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Eye gaze is a powerful communication cue revealing one's emotions, intentions and focus of attention. Following the eye gaze of another person results in gaze-evoked shifts in attention and has been the focus of research for more than a decade. Previous research in joint attention has shown that objects that are gazed at are more liked than objects that do not receive attention. Here, we investigated this gaze-cueing effect on participants' willingness-to-pay judgements for unknown snack products. Thirty-two participants initially rated their willingness to pay, the tastiness and the healthiness of unknown snack products. This was followed by a gaze-cueing paradigm in which a face either always gazed at the product (congruent condition), gazed away from the product (incongruent condition) or gazed at the participant (neutral). Following the gaze-cueing procedure, participants once again rated the snacks for the same three questions. We observed standard gaze-cueing effects with reaction times being the fastest in the congruent condition ($F(2,62) = 48.73$, $p > 0.001$). Importantly however, we also observed a significant effect of gaze cueing on participants? willingness-to-pay judgements, such that it increased for the products in the congruent condition while they decreased in the incongruent and neutral conditions ($F(2,62) = 5.33$, $p= 0.007$). Interestingly, this increase in willingness-to-pay occurred without participants? awareness. These results highlight the influence of social information on human choice behavior and lay the foundation for further experiments in neuromarketing and consumer decision making.

1-M-45 A behavioral and neural study of motivations for deception

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Objective: Deception plays a big part in social interactions, from mundane white lies up to multimillion dollar frauds. While from a utilitarian stand-point, people should lie whenever they can benefit from it, in reality this is not the case. For example, studies showed that people incorporate into their decision process the consequences of their lie on others. In this study, our objective is to identify the internal motivations that contribute to the decision to deceive another person, and outline the neural correlates of dishonest behavior. Methods: We used a task called The Message Game, in which a subject (Sender) sends out either a profitable yet deceptive message or a truthful but not-as-profitable message to another participant (Receiver). Payoffs varied across trials, in order to assess individual sensitivity to different motivations for deception. We defined three such potential motivations: Self Interest, Regard for Other, and Inequality. Thirty-three subjects completed the task, while their neural activity was

recorded using an fMRI scanner. Results: Behaviorally, we found that on average participants sent a deceitful message on half the trials. However, this behavior varied dramatically between subjects, and while some lied on nearly every single trial, others scarcely did so. Further subject-level analyses revealed high variability in motivations as well, both in which motivations drive the behavior and to what extent. On the neural level, we observed several regions implicated in the decision to deceive, including the superior temporal sulcus, posterior cingulate cortex and the temporoparietal junction (TPJ). Interestingly, we were able to identify motivation-specific regions of activations, modulated by how these motivations affects individual subjects' behavior. We found utilitarian considerations to correlate with activity in several regions, including the lateral prefrontal cortex, while other-oriented motivations involved differential activity in regions such as the TPJ, dorsal prefrontal cortex and anterior cingulate cortex. Finally, we show that the connectivity between these social and utilitarian regions is associated with subjects' behavior as well. Conclusion: Our results suggest that different people have different motivations to act honestly. Importantly, these differences may be traced to specific neural structures and connections.

1-M-46 Effects of stress on neural patterns underlying reward anticipation for self and others

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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 emotions. Intriguingly, several behavioral studies have shown that prosocial behavior can increase under stress. Furthermore, in a recent fMRI study, we found that magnitude of activation in empathy for pain areas increased under stress, which correlated with later prosocial behavior. This, however, poses the question whether increased emotion sharing under stress might be restricted to negative emotions. More specifically, in a "misery loves company" fashion, stress might increase a proneness to share negative emotions with others. However, it might as well be that stress increases general emotion sharing and by this prosociality. We aimed to investigate this research question by assessing how stress modulates emotion sharing for positive emotions. We focused on the domain of reward due its powerful effects on motivated behavior and investigated how stress affects neural mechanisms underlying reward anticipation for self and others. Methods: We used fMRI to assess effects of stress on neural patterns underlying reward anticipation for self and for others. Psychosocial stress was experimentally induced in using a well-established stress paradigm (i.e. Montreal Imaging Stress Test, MIST). Participants (N=30) underwent both, a stress and a control condition and subsequently completed a gambling task in which they decided to play gambles for themselves or for another participant. We compared distinctness in neural patterns in vmPFC between self and other during stress and control condition in each participant using representational similarity analysis (RSA). Results: While under stress, participants showed lower differentiation between self and other in the high reward domain while differentiation between self and other in the low reward domain remained unaffected. Discussion: Our results imply that under stress participants differentiate less between the target of the reward (i.e., self or another person) when anticipating high rewards. This proposes a potential underlying mechanism for why individuals become more prosocial under stress: If stress reduces differentiation between self and other during reward anticipation, actions performed for others might become more rewarding for oneself. This has crucial implications for our understanding of how stress affects social cognition and social decision making.

N – Valuation & Value Systems

1-N-47 Value updating and encoding in distinct subregions of dACC during effort-based decision-making

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Integrating cost and benefit information is crucial for optimal decision-making. Prior work suggests that effort-based decision-making relies on a distributed network comprised of ventral medial prefrontal cortex (vmPFC), cingulate cortex, striatum, anterior insula (AI), and supplementary motor area (SMA). To date, however, it is unknown, whether computations performed by these regions are involved in comparison of effort, reward, or their integration. Here, we scanned 29 healthy participants while they completed a novel sequential effort-based decision-making task. Cost/benefit information was presented using a staggered design across two cues (Cue 1 and Cue 2) that contained trial-wise reward or effort information. This design uniquely allows for the isolation of neural responses to effort or reward alone, as well as to their subsequent integration. A two-parameter power function was fitted to each subject to determine trial-wise subjective value (SV) estimates. We also used a sliding window analysis to examine correlates of participant's expected subjective value at Cue 1, as well as their subsequent updating in response to Cue 2 information. Across all subjects, dACC, striatum, SMA, and AI were active during choice, supporting these regions' roles in an effort-based choice network. Within dACC, we observed distinct subregions engaged in the encoding of decreasing reward and increasing effort values separately, choice difficulty, and value updating. We also observed that chosen SV was associated with vmPFC, while ventral striatal activity was associated only with the magnitude of reward. Taken together, these results demonstrate a spatially distributed network of areas that respond to separate elements of effort-based decision-making. Specifically, dACC subregions encode both value and choice signals over the course of our sequential trial design, highlighting this region as a potentially integral hub in this network.

1-N-48 Neural Currency: Domain General Neural Map of Value Predicts Choices Across Subjects and Across Tasks

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Objective: Many studies have identified brain activity that correlates with subjective value in overlapping brain areas across subjects (e.g., ventral striatum and ventromedial prefrontal cortex) across a wide variety of tasks (e.g., economic decision-making tasks, consumer good purchases, food choices). However, a strong test of a "common neural currency" or domain-general neural correlate of value would be showing that neural activity in these regions can be used to predict choices across people and tasks. To date, though, most studies have focused on neural prediction of choices within subjects. Here we test whether we can build neural predictors that generalize across subjects and tasks. Methods: 99 subjects performed intertemporal choice and risky choice tasks while undergoing fMRI. We used PCA combined with binary logit models to build a whole-brain "neural signature" of choice. This map identifies all areas that are monotonically correlated with choice probabilities. We then systematically evaluated prediction performance across: 1) within-person vs. across-person prediction (i.e., the map is trained on one person and tested on another), and 2) within-task vs. across-task prediction (i.e., the map is trained on intertemporal choice data and used to predict risky choice, or vice versa). Results: We found above chance neural prediction that generalized across both subjects (i.e., the map is trained on one person and tested on another) and across tasks (i.e., the map is trained on one choice task and used to predict another). Interestingly, across-subject generalization appears to be the more difficult roadblock, as (1) same-subject-across-task prediction leads to higher performance than across-subject-same-task

prediction and (2) across-subject-same-task prediction accuracy is similar to across-subject-across-task prediction accuracy. The brain areas that exhibit the most significant weights in the "neural signature of choice" include the expected regions in ventral striatum and medial prefrontal cortex. Conclusion: These results provide some of the strongest evidence yet that there is a common neural signal of value that generalizes across people and across decision-making tasks. The ability to decode choice intentions across people and domains could lead to numerous applications in economics and marketing research.

1-N-49 Improving Preference Modeling for Multi-Criteria Decision-Making with Cognitive Mechanisms Analysis

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Multi-Criteria Decision Making or Aid (MCDM/A) deals with problems with multiple objectives, evaluated in a set of attributes. Multi-Criteria problems are common in professional and personal situations and in most cases represent a complex situation. These problems require a large cognitive effort by decision makers, in order to cope with their preferences within the model. Objective: The aim of this study is to evaluate in which conditions graphical visualization can be appropriate to shorten the preference elicitation process, reducing the cognitive efforts and consequently avoiding errors in the process. Method: Two sequences were constructed to represent different decision situations of visualization in FITradeoff method (an MCMDM/A method), which is implemented in a Decision Support System (DSS). The graphics applied were independents of each other and presented some variation in the number of items (combining alternatives and criteria) and two different patterns of criteria weights (equal and decreasing values). While undergoing eye tracking, forty four subjects analyzed these sequences. Sequences with both same criteria weights and different weights have been analyzed. The subject indicated the best alternative in order to evaluate hit rate and associated conditions. Results: Changing in hit rate has been associated with different conditions, such as: the number of items (with combination of alternatives and criteria), fixation region, pupil diameter, pattern of criteria weights, processing time, and so forth. The pattern of equal weights compared with decreasing weights occasioned a hit rate decrease in 12%, mean of fixation duration increased in 20%, fixation count mean increase in 12%, visit duration increase in 19% and visiting count mean being equivalent. The recording duration, time to complete all sequence, decreased 25% in the second pattern and the pupil diameter left increase 5% and right increase 7%, in the second pattern. Conclusion: Results are being applied in the improvement of the design of the DSS for FITradeoff method, contributing to the enhancement of the decision analysis process. However, it has been observed that additional analysis should be conducted in order to evaluated effects of learning curve process duration the experiment and how tiredness can affect the results of the decision process.

1-N-50 The neural correlates of appraisal versus choice

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Objective: As illustrated by the distinction between buying versus "just browsing," people can evaluate potential rewards with or without the intent to choose between them. A common reward network has been implicated across these two decision settings, including regions of ventromedial prefrontal cortex and the posterior midline. Recent work has begun to structurally and functionally dissociate sub-components of this reward network, distinguishing an "mOFC Network" (including medial orbitofrontal cortex mOFC, retrosplenial cortex, and middle frontal gyrus) from an "rACC Network" (including rostral anterior cingulate cortex, ventral striatum, and posterior cingulate). Past findings involving these two networks suggests that the rACC Network may play a relatively automatic role in appraising one's

options whereas the mOFC Network may instead be more involved in choice comparison. Here we test this hypothesis directly by manipulating an individual's goals when approaching a set of valuable items. Methods: On each trial of this fMRI study, participants (N=27) were presented with sets of four common products and were instructed to either appraise how much they liked the set (Like), or to choose their most preferred product from the set (Choose). Results: We found that set appraisal was driven by the average value of the individual items in a set, and correlated with activity in the rACC Network. Critically, this network tracked set liking both when task-relevant (Like trials) and when task-irrelevant (Choose trials). In contrast, the mOFC Network was particularly sensitive to task condition, significantly more active during Choose than Like trials. Modeling mOFC and rACC activity in the same regression, we find a dissociation whereby mOFC is selective for evaluation type (Choose vs. Like) but not overall set liking, whereas the reverse was true for rACC. In addition, rACC but not mOFC also tracked task-specific estimates of how certain the participant was in the (Like or Choose) evaluation they were making on a given trial. Conclusions: These findings are consistent with the possibility that different neural circuits involved in appraising the overall value of a set of options versus selecting a preferred option from the set. The rACC Network signals set liking whether appraising or choosing, suggesting that it may signal an automatic affective response to those options (regardless of the individual's specific evaluation goal); these affective responses may encompass feelings of certainty or confidence once either decision is made. In contrast, the mOFC Network is engaged when comparing between options, rather than summing across them.

1-N-51 Electrocortical correlates of willingness-to-pay: an event-related potential study.

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The value of environmental cues and internal states are continuously evaluated by the human brain, either consciously or sub-consciously. Ultimately, it is this subjective value that guides the decision making process. The present study aimed to investigate the spatio-temporal aspects of brain economic valuation using electroencephalography. Participants completed a stimulus rating task in which decisions where either value-relevant (desirability) or -irrelevant (material estimation). Willingness-to-pay (WTP) values were used as a measure of subjective economic value for the stimuli, obtained using the Becker-DeGroot-Marschak (BDM) auction. The stimulus set comprised everyday household items valued up to £4, split into high and low value based on subjective WTP values. A sequential strategy was used to examine value-induced modulation of event-related potential responses to stimulus presentation. Source dipole modelling was applied to estimate the cortical sources underlying effects of WTP (high vs. low) and the evaluation condition (value-relevant vs. value-irrelevant judgments). Source activity was greater for low value items than for high value items in the right anterior insula and the left orbitofrontal cortex. Source activity was also greater in the left lingual gyrus, right anterior insular cortex and right parahippocampal gyrus for the desirability rating condition than for the material estimation condition. These effects were all observed within the latency of the P2 and N2 components at approximately 200ms. Findings suggest a negativity bias towards low value items, possibly due to the low value items presenting a source of potential financial loss. The insula is well established as being the centre for risk and loss aversion and could potentially explain this finding. The importance of the right anterior insular cortex and the right parahippocampal gyrus in economic decisions is apparent with facilitated source activity in these regions when value was relevant.

1-N-52 Shifting Preferences by Verbal Cueing during Sleep

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Objective: Decisions can be altered without external reward reinforcement or direct manipulation of option values. Recent studies have shown that interventions targeting sensory information processing or associative memory can perturb behavior by modulating the underlying preference. On the other hand, converging evidence suggested that subtle reminders during sleep (e.g. sensory cues to recent learning while asleep) can substantially enhance performances in a variety of cognitive tasks, sometimes more effectively than reminders presented while awake. Here we explored the extent to which verbal cueing during sleep could impact value-based decisions. Methods: 92 subjects participated in the study. Subjects were first introduced to 60 snack items and indicated their willingness-to-pay (WTP) in a Becker-DeGroot-Marschak auction, where the spoken name of each item was delivered over a speaker. During subsequent sleep, names of 8 items (i.e. cued items) were presented repetitively at the non-rapid eye movement stage 2 sleep. To assess the effect of verbal cues on preference for cued vs. uncued objects, we reevaluated WTP after waking, followed by a binary decision task between cued vs. uncued snacks matched for initial WTP. Participants in the wake condition underwent the same procedure but, rather than taking a 90-minute nap, they were kept awake for the same duration of time. Sleep monitoring was performed with standard polysomnography recordings. Results: Our results suggested that the subjective value of snack items could be modulated by presenting the spoken name of a snack during stage 2 sleep ($t(46)=6.08$, $P<0.001$). In contrast, the same verbal stimulation during wakefulness produced no significant change in preferences for cued, relative to uncued items. Electrophysiological results showed that cues during sleep elicited stronger event-related synchronization for the low-frequency band such as delta band, which has been previously implicated in the detection of motivationally salient stimuli. Importantly, the power of delta band induced by verbal stimuli during sleep strongly predicted the degree to which preferences were enhanced ($r=0.65$, $P<0.001$), suggesting the involvement of neurocognitive processing during sleep in shaping preferences. Conclusions: These findings indicated that sleep might represent a unique period during which preferences can be selectively modified by external cues. Our approach was built upon recent evidence on targeted memory reactivation, adding a critically component of decision-making. Results of the study may provide insights for the dependency of goal-directed behavior on memory, pointing to a potential possibility for nudging behavior with subtle manipulation of memory processing during sleep.

2-B-1 Framing effect of the value representation of bundles of goods

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Since Kahneman and Tversky (1979) proposed prospect theory, studies in the field of decision-making have widely accepted the proposition that framing a decision in the gain or loss domain changes individuals' preferences. Kahneman and Tversky presumed that people have asymmetric utility functions for choices over gains and losses - concave utility over gains and convex utility over losses (also known as diminishing sensitivity). What is less known is that such utility functions predict paradoxical behavior in the context of deterministic choice over bundles (collections) of goods. Specifically, prospect theory predicts that in the loss domain people prefer retaining all of one type of good to any mixed bundles. Surprisingly, however, there have been no empirical investigations of this non-intuitive prediction and only a few studies of diminishing sensitivity from the reference point under riskless choices in general. In this study, we aim to investigate the value representation of bundles at both behavioral and neural levels. Our novel design allowed us to estimate utility curvature for gains and for losses with minimal assumptions on the structure of the underlying choice model. We estimated utility curvature in two tasks: (1) riskless choice over bundles of goods and (2) risky choice over bundle lotteries. In the riskless task, bundle composition varied from trial to trial but the outcome is deterministic. In the risky task, the bundles were received with some varying probability. Both our risky and riskless trials involved choices over bundles composed of the same goods and have approximately equal expected value. The visual stimuli were identical in both conditions and participants were instructed similarly in all tasks to make a series of choices between two options. We designed the tasks to be identical in everything other than the probabilistic versus certain nature of the decision. Our behavioral results show that diminishing sensitivity does not generalize - choices over riskless bundles are not gain-loss context dependent. This occurs even though the same subjects show the traditional framing effect when making risky choices. In addition, the non-parametric model-free analysis confirms our model-based results. Our goal is to probe this discrepancy at a neural level with imaging data. Our preliminary fMRI data confirms our behavioral finding that at least for the large class of goods of the type that we examined, prospect theory appears to make inaccurate predictions about the nature of valuation in the loss domain. The imaging data suggests that distinct brain circuits may be involved in different contexts.

2-B-2 Cognitive Analysis for Improving Preference Elicitation Confidence of Scale Constants in Multi-Attribute Value Theory

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The elicitation of scale constants of attributes is one of the most relevant issues in Multi-attribute decision process, when dealing with problems with multiple objectives. These problems are constantly present in any organization. Decision problems with multiple objectives demand an important cognitive effort for preferences elicitation with decision makers. The confidence of this elicitation process is crucial for the quality of decision making and success of organizations. However, studies in literature have reported many inconsistences in main elicitation procedures. Objective: This study intends to contribute with the reduction of inconsistencies of preference elicitation process of scale constants of attributes for additive models in Multi-attribute Value Theory (MAVT) scope, by obtaining recommendation for the design of decision support system (DSS) based on the analysis of cognitive mechanism during these processes. Method: Fifty five undergraduate and master students participated in an experiment using

eye tracking system and a DSS built to conduct the elicitation process of scale constants of attributes in MAVT. The DSS analyzed is based on a method for flexible and interactive tradeoff elicitation procedure. Different interface structures are built for the DSS in order to compare their performance of the elicitation process of scale constants. These structures are based on either numerical or graphical information, which are shown to the subjects in order to compare the way in which they provide information of their preferences. Different instances of outcomes with number of attributes varying from three to seven are considered. The subject indicated the preferred outcome and the consistencies with the MAVT were checked. Results: The degree of consistence is checked with the additive model in MAVT scope, comparing the results for different outcomes analyzed. Changing the structure of information for the DSS it can be observed different conditions for pursuing recommendations toward the design of the DSS interface. These conditions include: fixation region, pupil diameter, number of attributes, processing time and degree of consistence for choice of outcomes. Conclusion: Results are applied for supporting analysts in their interaction with decision makers and for the design of DSS for flexible and interactive tradeoff elicitation procedure. This contributes significantly to the enrichment of the consistencies in the elicitation process. However, although the use of graphical information has been increasable indicated as a better source of information compared with numerical information on tables for the analysis of outcomes, it has been observed that this is not always the case for natural attributes.

2-B-3 Combining computational modeling and EEG to understand how reinforcement learning influences the decision process

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Recent work in computational modeling has focused on describing decisions as a dynamical process of evidence accumulation. More traditionally applied to perceptual decisions, this approach has also been successful in explaining economic (value-based) decisions in descriptive tasks (i.e., when participants are informed about the values associated with various options). The goal of the present study was to test evidence accumulation models in an economic decision-making task that requires to learn values from feedback, and to map learning-dependent changes in the model onto its neural correlates. We had participants performing a gambling task in which the first option had known outcome probability and magnitude, and the second option had known probability but the magnitude had to be learned based on feedback. The mean magnitude of the second option oscillated slowly over multiple trials from high to low. Results from a behavioral pilot study (n = 18) showed that participants integrated probability and magnitude of the outcomes and kept track of the changes in the second option: The second option was preferred when its magnitude was higher, and response times became faster after a change in the magnitude mean. To explain these behavioral effects, we tested different Reinforcement Learning Diffusion Decision Models (RLDDMs), using hierarchical Bayesian parameter estimation. RLDDMs combine a reinforcement learning mechanism with the evidence accumulation framework, thus providing a comprehensive and dynamic account of the decision process. The winning RLDDM assumes that the accumulation rate is proportional to the difference in expected values, and that the expected value of the second option is updated depending on a learning rate parameter. The starting point of the decision is biased by the learned values and the threshold depends on decision conflict. We then fit the winning model to the behavioral data from an EEG experiment (n = 33). The model provided a good account of accuracy and response times. Based on this model, we expected the lateralized readiness potential (LRP) to emerge already when only the positions of the options (left versus right) but not the probability of the outcomes were revealed. This prediction was confirmed. Further preliminary results showed a weak, positive correlation between the individual LRPs and the individual starting point bias

predicted by the RLDDM. This study is the first to combine reinforcement learning and diffusion modeling in a gambling task with a dynamic environment. By combining parameters estimates and EEG data, we were able to test some of the model's predictions and provide a mechanistic explanation of the decision process in this task.

2-B-4 The domain-specific causal role of the left dLPFC in evidence accumulation in perceptual decisions

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Across all decision domains, all organisms seek to optimize choice outcomes. Careful deliberation of alternatives yields more evidence accumulated and better outcomes. Impulsive decisions gather less evidence and suffer more suboptimal choices. However, it remains poorly understood whether the decision mechanisms maintaining optimal decisions are specific to one decision domain or general across many. In perceptual decision making, the left superior frontal sulcus (SFS) plays a central role in maintaining optimal decisions, but whether it is involved in value-based decisions remains unclear. Combining neuroimaging and a hierarchical drift-diffusion model, we non-invasively stimulated the left SFS of healthy participants while they performed a matched perceptual and value-based decision task. Inhibiting the left SFS led to greater impulsivity in perceptual decisions as participants had more errors and faster response times. Stimulation did not affect accuracy in value-based decisions, but spilled over faster response times. Perceptual impulsivity is reflected as: (1) reduced decision thresholds in our computational model; (2) reduced neural activity in the stimulated area; and, (3) increased functional connectivity between the left SFS and downstream areas of the visual cortex. These results reveal a causal mechanism of the left SFS in maintaining optimal perceptual decisions by showing how its impairment lead to domain-specific sub-optimal impulsive behavior.

2-B-5 Increased baseline arousal both precedes and mediates exploratory behavior

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Objective: The ability to alternate between exploratory and exploitative modes of action is critical for the maximization of long-term rewards. Adaptive gain theory (AGT) posits that switches between exploration and exploitation are mediated by a norepinephrine-based arousal system that responds to changes in the expected utility of selecting an action. Recent studies suggest that the activity of this norepinephrinergic (NE) system can be assessed indirectly by measuring pupil diameter (PD). Here we used a combination of fMRI, computational modeling, and pupillometry in humans to test two key predictions of the AGT: 1) exploratory choices are preceded by both higher pre-stimulus baseline arousal and concomitant activity increases in brain areas previously associated with value-based decision-making over a sustained period, and 2) previously reported influences of continuously monitored decision variables on choice behavior are mediated by pre-stimulus baseline arousal. Methods: Participants (N=66) played a restless bandit task while undergoing simultaneous fMRI and PD measurements. Exploratory choices were classified using a reinforcement learning model. Changes in PD and neural activity were examined in the baseline period preceding exploratory vs. exploitative decisions, both for the current trial and for the 6 preceding trials. Results: Baseline PD was indeed increased prior to exploratory vs. exploitative choices (from 2-0.58 seconds pre-stimulus, cluster-based permutation t-tests, permuted $p < 0.001$, cluster-forming $t = 3$). This was already evident up to two trials prior to any given exploratory choice (average PD in 1s windows before stimulus onsets, all $t > 3.1$, corrected $p < 0.05$, note that participants mostly exploited on these previous trials). As predicted, baseline arousal mediated the influences of continuously monitored decision variables (reward

magnitude of the current best exploratory option, prediction errors on prior exploratory choices) as well as the previously received payoffs on choice (Sobel tests: all $z > 2.04$, $p < 0.05$). Lastly, neural activity in frontopolar cortex, as well as the middle frontal, and precentral gyri, showed corresponding activity increases in the baseline period up to one trial before exploratory choices, despite these trials generally being associated with exploitation. Conclusions: These results demonstrate that both pre-stimulus baseline arousal and neural activity in regions associated with exploration show an extended increase prior to exploratory choices. This provides novel evidence for the central prediction of AGT that exploratory behavior is triggered by context-adaptive responses of the norepinephrine-based arousal system.

2-B-6 Attention and value integration in multi-attribute choice

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OBJECTIVE Some of the most important decisions we make on a daily basis involve the complex consideration and (noisy) integration of multiple attributes rather than a single discrete value. However, the computational process by which these multi-attribute values are constructed remains poorly understood. How are different attributes attended, and what shapes the relationship between an attribute's value, its weight, and the attention it receives? To answer these questions, we develop a computational model that describes the dynamics by which people search and attend to multiple attributes in a value-based decision making task as a function of their value and weight. METHODS 21 participants completed a multi-attribute choice task. On each trial, participants saw an image combination consisting of a house and a face. Each house and face was associated with a different positive or negative value, and the combined value of the two images determined the overall value of the option which subjects could decide to accept or reject. To manipulate the weight, or importance, given to the face and house, a number placed above each image signaled by how much the the image's original value would be multiplied. To examine how values and weights influenced attentional allocation, participants could observe only one attribute (either the face or house) at a time. Participants pressed a button to switch between the two attributes, allowing us to measure when and for how long they chose to attend to each dimension. We used these observations to develop a computational model describing both choices about what to attend, and whether to accept or reject the option. RESULTS Behaviorally, participants achieved accuracy rates of over 80% and demonstrated reaction times (RTs) and accuracy that aligned with predictions: increased ambiguity/difficulty resulted in increased RT and lower accuracy. RTs were also significantly affected by weighting. Among trials with 0, 1 or 2 multipliers we found that those with a single multiplier had the shortest RT and those with two multipliers had the longest RT. We find that a two-stage drift diffusion model captures patterns of attention and choice. More specifically, decisions about both what attribute to attend, how long to attend to it, and what choice to make, were shaped by a combination of the attribute's value and its current importance. CONCLUSIONS Our data inform models of attentional allocation to different attributes during value construction. They suggest that attention itself is a value-based choice informed by context-dependent attribute weighting. EEG and fMRI data collection to further elucidate neural mechanisms is ongoing.

C – Computational Modeling

2-C-7 Computational Modeling of the Effort Expenditure for Rewards Task

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The objective of this study is to dissociate sensitivity to effort from other influences in the Effort Expenditure for Rewards Task (EEfRT; Treadway et al., 2009), a task that has been widely used to evaluate

motivational deficits but has not yet been fit with computational models. While prior studies have focused on a relatively simple proportion of high-effort to low-effort choices, the application of computational models can provide more precise measures of effort sensitivity, allowing us to distinguish sensitivity to effort from other factors that frequently influence task performance, such as sensitivity to reward and probability, decision consistency, and random responding. We test the fit of a subjective value model in a large sample of previously collected data, showing that our model provides a better fit than a baseline (fixed probability) model in > 90% of participants. We then apply our model to clinical samples (major depression, schizophrenia) and simulate data using model-derived parameters to show that observed performance differences between patients with major depression and schizophrenia are related to increased effort-related devaluation of reward relative to healthy controls. We also show that parameterized effort sensitivity is related to increased self-reported symptoms of anhedonia. Implications for using effort-based decision-making as a model of motivational deficit across diagnostic categories will be discussed.

2-C-8 Estimating the costs of cognitive control: theoretical validation and potential pitfalls

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Objective: Cognitive control is critical for accomplishing daily tasks and yet we experience it as costly/ effortful. Researchers have been increasingly interested in estimating just how costly cognitive control is for a given individual, in order to better understand underlying mechanisms and predict motivational impairments outside the lab. Here we leverage an economic model of control allocation to (a) demonstrate how an individual's control cost function can be estimated from task performance and (b) highlight the conditions under which such costs will be confounded with other motivational variables (e.g. sensitivity to reward). We show that poorly calibrated estimates of these other variables can lead to cost estimates that are quantitatively or even qualitatively different than their true values. Methods: We simulated agents performing cognitive control tasks while trying to maximize expected returns and minimize control costs (Musslick, Shenhav, Botvinick & Cohen, 2015, RLDM). We then tested our ability to recover the agent's (known) control cost function based on observed task behavior, as we varied other internal variables describing how the agent processes their environment: task automaticity (quality of task performance in the absence of cognitive control), control efficacy (degree to which increased control increases the likelihood of reaching one's goal), reward sensitivity (utility of monetary rewards), and accuracy bias (intrinsic reward for performing accurately). We then tested our ability to accurately recover an agent's true control costs as our assumptions about these other parameters deviated from their actual values. Results: When we assumed that we had perfect knowledge of the other internal variables (task automaticity, etc.), our estimation procedure successfully recovered the control cost function for the agents. However, if we assumed imperfect knowledge of these variables, the inferred control cost estimates rapidly deviated from their true values. Critically, they could even suggest the opposite cost profile for an individual. For instance, an agent with a high cost of control appeared to instead have a low cost of control if the agent was high in task automaticity. Conclusions: We show that individual differences in the costs of control can be inferred from an individual's behavior, but the validity of those estimates depends heavily on an experimenter's ability to estimate other cognitive/motivational variables. More generally, we provide a method for quantifying limits on the validity of a given measure of task performance (e.g., Stroop interference) as an individual difference measure for a given cognitive variable.

D – Consumer Behavior & Marketing

2-D-9 Different EEG metrics and Machine Learning Techniques have varying levels of predictive accuracy of subject?s future preferences and population commercial success

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Objective: In the last five years, academic studies demonstrated, using mainly fMRI and EEG, the ability to predict future marketing success to some degree, and in some cases even above and beyond standard questionnaires. However, most of these studies based their analyses solely on regression models. Moreover, in each of these studies only a single type of neural measurement was used, such as average BOLD signal, specific EEG spectral frequencies, alpha frontal asymmetry, or inter-subject coherence. Because of this wide diversity, it is hard to draw a conclusion regarding the total extent of successful prediction, which measurements are most useful, what computational models are best, or when and why there are failures in predictions. Therefore, in the current study we sought to examine various computational and statistical approaches, applied on a large variety of EEG based neural features, eye tracking features, and image features, in order to test the strengths and weaknesses of each method and data type. Methods: Towards this aim we measured 31 subjects' neural activity using EEG and eye movements, while subjects passively viewed different food product commercials. Thirty minutes after the recording session, subjects participated in a binary choice task, where they chose their preferred product between all possible pairs of products that appeared in the commercials. Lastly, subjects filled a standard marketing questionnaire on all commercials. In addition, we gathered population level metrics regarding the success of each commercial. Results: We describe our attempts to predict future preferences within individual subjects and marketing success in the general population, using various methods and measurements. Our general finding is that some methods and data types had some contribution to prediction by themselves, such as frontal delta and gamma asymmetry, intrasubject coherence, and lower-frequency band means. Furthermore, we found that complex tree-based machine learning approaches yielded better prediction than standard SVM or regression models. Other measurements were entirely redundant compared to prediction from questionnaires. Conclusions: Most importantly, we found that there was no one-method-fits-all solution for all cases, but rather a combination of computational methods and neural measurements were necessary to improve predictions beyond traditional measurements.

2-D-10 Sharing More than We Mean to Bare: Neural Mechanisms Underlying the Privacy Paradox

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Consumers increasingly search, buy, review, and connect online. As a result, concerns about privacy have become prominent. Yet while people report privacy is important to them, their behavior often does not reflect those concerns. We hypothesize that this privacy paradox arises because consumers often share information in order to receive benefits (e.g., loyalty rewards). We hypothesize that consumers focus on the benefits' value and neglect their privacy concerns, leading to the disclosure of private information. We test this hypothesis across two behavioral experiments and one neuroimaging experiment. 37 participants completed Study 1. First, participants separately rated the attractiveness of benefits (e.g., "Free Shipping") and the intrusiveness of questions (e.g., "What is your Social Security Number?"). Participants then viewed both a question and a benefit together and rated how willing they would be to answer the question honestly in order to receive the benefit. Analyses regressed participants' willingness to disclose their private information on their previous ratings of the question's intrusiveness and the

benefit's attractiveness. The more attractive the benefit was, the more willing participants were to disclose the information, p=.001. However, the question's intrusiveness did not influence participants' willingness to answer, p>.8, indicating that participants only weighed the benefit in their disclosure decisions and neglected information about intrusiveness. In Study 2 we evaluated whether consumer education might resolve the privacy paradox, with half of the participants learning about the risks of sharing private information before the task. A repeated-measures ANOVA again revealed a main effect of attribute, p<.001, with the benefit influencing decisions, p<.001, while the question's intrusiveness did not, p>.5. However, neither the main effect of condition nor the interaction was significant (p's>.7), indicating that education about privacy risks did not alter how information was used when deciding to disclose information. Participants in Study 3 underwent function magnetic resonance imaging while performing the task. Analyses revealed that activation in ventromedial prefrontal cortex and striatum tracked the perceived attractiveness of the benefits. Activation in insula and anterior cingulate cortex tracked the perceived intrusiveness of the questions. Activation in parietal and prefrontal regions integrates these signals to guide disclosure decisions. By clarifying the neural and psychological basis of the privacy paradox, this work can inform behavioral interventions to help consumers protect their privacy in online markets.

E – Emotion & Affect

2-E-12 An integrated approach toward the understanding of affective influences on reward-based decision making in patients with schizophrenia

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Deficits in emotion recognition and decision making are two of the signature symptoms in schizophrenia. Studies have shown that patients are less accurate in recognizing faces with negative emotions than with positive ones, especially for the fearful and angry expressions. On the other hand, the updated reward prediction error (RPE) - a discrepancy between the predicted and actual action outcomes - is thought to be encoded by dopaminergic neurons, and the dysregulation of dopamine systems in schizophrenia has been suggested to alter the appraisal of stimuli, leading to the abnormalities in reinforcement learning and decision making. These two deficits, however, have seldom been incorporated together into clinical study. Accordingly, this study aims to investigate the impact of emotional experience on decision making in schizophrenia. Specifically, building on our previously established paradigm, we took three basic facial expressions - neutral, anger, and happiness - as the affective primes inserted into a probabilistic gambling task, and examine their impact on choice behavior. In addition to conventional behavioral statistics, a reinforcement learning model was adopted to fit the participants' trial-by-trial choice data to assess their latent process involved in the task. Moreover, EEG recordings were implemented throughout the experiment to obtain the activities related to facial perception, affective arousal, and RPE signaling. For healthy controls, both anger and happiness facial primes elicited higher level of affective arousal than the neutral ones, and led to elevated RPE signaling, rendering the participants to update expected values more frequently and make more exploratory choices. Conversely, in schizophrenic patients, the baseline of RPE signaling was contingent to their symptom severity, and, importantly, only the happiness facial prime yielded significant modulatory effect on choice behavior due to patients' less-accurate recognition to negative emotions. Findings of this study shall contribute to our understanding of the mechanism underlying affect-elicited decision making in schizophrenia.

2-E-13 Neural basis of perceived unfairness in Bipolar Disorder: an fMRI study using the Ultimatum Game

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Two prominent clinical features of Bipolar Disorder (BD) are the elevated anger and the emotion regulation deficits. These two clinical features may contribute to the social deficits that characterize BD patients. An interesting and relatively unaddressed question is how BD patients process unfairness in social contexts. To date, only one study has examined the behavior of euthymic BD patients in such a context by using the Ultimatum game, a well-established social economic game that assesses responses to unfairness. In this study, BD patients displayed a similar pattern to healthy controls as they rejected overtly unfair offers and accepted fair offers. However, moderately unfair offers were more likely to be rejected by BD patients than healthy controls. Based on a dominant neurobiological model, processing of unfairness recruits an intuitive system for rapid evaluation and a deliberate system for integrating both fairness-related and self-interest calculations to regulate the intuitive system in favor of more flexible decision making. This dual systems hypothesis offers two alternative interpretations to the abnormal behavioral pattern of BD. In this respect, deficits in processing of unfairness may be the result of a hyperactive intuitive system that is sensitive to unfairness or alternatively it could be the result of impaired regulation of the elicited anger by the deliberate system. In the present study, we aim to address this question by investigating the neural responses to unfair offers in the Ultimatum game in a sample of 20 euthymic BD patients and 25 age- and gender-matched healthy controls. We hypothesize that BD patients will display an abnormal pattern of neural responses to both overtly and moderately unfair offers irrespective of the presence or not of behavioral abnormalities. If this deficit is driven by a hyperactive intuitive system, we expect to find abnormally increased responses in anterior insula and lower activation of ventromedial PFC. Anterior insula is associated with the visceral experience of negative feelings evoked by unfair offers and the violations of social norms. Ventromedial PFC is implicated in tracking the positive and negative values of different stimuli. On the other hand, impaired recruitment of dorsal anterior cingulate cortex, which is implicated in conflict monitoring, and lateral PFC, which is important for the implementation of emotion regulation strategies, may reflect inability of the deliberate system to regulate bottom-up responses to unfairness. Using the ultimatum game, the present neuroimaging study can provide novel insights into the underlying mechanisms and the neural systems that are implicated in the abnormal social behavior in BD.

F - Finance

2-F-14 The Effects of Psychological Distance and Incidental Affect on Economic Risk Taking and Temporal Discounting Behaviors

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Money is ubiquitous in modern daily life, but little is known about the relationships that exist between money and our emotions and decisions. This study tested the effects of two types of incidental affect--situational/state affect and dispositional/trait affect--on both economic risk taking and temporal discounting of financial rewards. Situational/state incidental affect was manipulated as the exposure to Philippine peso bills. Two forms of dispositional/trait incidental affect were examined--optimism and sensitivity to reward. Both forms of affect were incidental because they were unrelated to the decision alternatives and consequences and merely coincided temporally with the decision making process. The experiment assessed the significance of gender, the social form of psychological distance (i.e. social distance or self-other decision making), situational/state affect due to incidental exposure to a reward cue, and dispositional/trait affect in predicting risk taking and temporal discounting of financial rewards in a modified Trust Game. Data were analyzed using univariate analysis and multivariate analysis of covariance, with optimism and sensitivity to reward as covariates. The Wilks' Lambda multivariate test of

overall differences among groups was found to be statistically significant for Optimism (p<.001), Sensitivity to Reward (p=.050), and the interaction between Psychological Distance and Situational/State Affect due to Reward Exposure (p<.001). Results suggest that risk-taking behavior was not significantly affected by psychological distance and situational/state incidental affect. But, risk taking was significantly related to the two covariates, both of which are measures of dispositional/trait affect, namely, optimism and sensitivity to reward. Whereas greater optimism was related to greater risk taking, greater sensitivity to reward was related to lesser risk taking. Temporal discounting decisions were significantly affected when these decisions impact the self, i.e. one tends to assign a higher value to immediate rewards over delayed rewards when one decides for the self. These observations are consistent with extant literature. Moreover, such a tendency to overvalue immediate rewards for the self becomes more pronounced when the decision maker was previously exposed to a rewarding stimulus such as money. This study further adds to the current body of literature in that it also investigated the effects of exposure to rewards on decisions for another person. In this regard, results suggest that one tends to assign a higher value to immediate rewards over delayed rewards when one decides for another individual but only when exposed to a neutral stimulus, such as paper, thereby expanding Loewenstein et al.'s Risk-as-Feelings model (2001).

G – Game Theory & Strategic Interactions

2-G-15 How bottom-up visual salience guides strategic choice in matching and hider-seeker games

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Game theory describes how strategic interactions lead to rewards, and makes predictions about likely strategy choices. It has been known for several decades that, in some games, how strategies are described or mentally represented can influence strategy choices (e.g., Schelling 1960). For example, if two players are trying to coordinate by matching their behavior (e.g., meeting at a common place, without communicating) then the psychological prominence or salience of strategies may influence choice. But there is no good theory of salience. Objective: We explore games in which two players choose a small area in a visual image. Bottom-up visual salience can be predicted from a ?graph-based visual saliency? (GBVS) algorithm. GBVS creates a activation maps using a Markov chain based on dissimilarity, and normalizing by concentrating mass on certain activation maps. The result is an ?end-to-end? algorithm that can take visual images as input and produce a 0-1 salience level for each region in the image. Method: Two players see 129 visual images (chosen from Google images). They play in three conditions (for $)?(1) against a random computer choice, and against another person both (2) with and (3) without feedback. Choices are Gaussian filters around a mouseclick location. If players choose randomly they will match 6.4% of the time. Results: In the matching condition, they successfully match 67% of the time. There is a very strong correlation between saliency and location choices (which is enhanced a bit by feedback). This confirms the long-standing intuition that prominence or salience will guide choices, but goes further by showing that choices are consistent with a freestanding measure of salience (GBVS) (which is independent of subject gaze and choice). In the hide-seek condition, if location choices match then the seeker player wins. If they mismatch the hider wins. Equilibrium game theory makes a clear prediction here: Players should randomize equally across all locations, and the match rate should be 6.4%. But seekers win 9.6% of the time. This finding replicates a seeker's advantage seen in some behavioral studies. Further analysis suggests an interpretation: The hide-seek game is akin to a visual Stroop task. Hiders choose more salient locations more often (compared to the random benchmark), even though they understand that their goal is avoid the seeker's location. Conclusion: This

study provides the first evidence, grounded in many visual cognitive neuroscience studies, about how salience can be measured computationally and can influence behavior in strategic choices. In this case, cognitive neuroscience helps solve a long-standing problem in game theory (i.e., what is salience).

2-G-16 A Mechanism for Eliciting Value Measurements Without Behaviour

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Objective Many studies have shown that measurements of neural activity correlate with long-standing behavioural measures of value (Bartra, McGuire, & Kable, 2013), particularly when behaviour is incentivized to be reported truthfully via a "BDM" auction (Becker, Degroot, Marschak, 1964; Plassmann, O'Doherty, & Rangel, 2007). Moreover, measurements made in the absence of choice behavior can predict future choices (Levy, Lazzaro, Rutledge & Glimcher, 2011; Smith et al., 2014; Telpaz, Webb, & Levy 2015), though with a significant amount of measurement error (Webb, Levy, Lazzaro, Rutledge & Glimcher, 2017). However in this latter set of studies, subjects were not incentivized during the measurement of value, suggesting it might be possible to improve existing measurement methodology. In the economics literature, mechanisms exist to induce subjects to reveal their true valuations in a variety of settings (Roth, 2002), and recent studies in neuroeconomics have suggested that behaviour combined with neural measurements can address some of the well-known deficiencies of these mechanisms (Krajbich, Camerer, Rangel, 2015). In this study, we explore the possibility of eliciting incentivized neural valuations without the requirement of behaviour. Methods & Results We show theoretically that in a "Neural BDM", subjects will report their true valuation when the price is drawn from a uniform distribution, but only for certain restrictions on the distribution of prices, f(p), and the distribution of error in the neural measurement, g(e). We describe some distributions for which this does not hold, such as when the domain of f(p) does not include the domain of g(e). We also have preliminary results that show the subject will not bid their true valuation when f(p) is increasing or decreasing. Taken together, these preliminary results suggest that the class of Neural Mechanisms in which agents are incentivized to truthfully report is limited.

2-G-17 Cooperative decision making in the prisoner's dilemma game across the lifespan

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Are we getting wiser with age? And does this lead to more cooperation as we grow older? Whilst the concept of aging and wisdom is accepted commonly, as the life expectancy is increasing, aging and social decision making has also captured the attention of psychologists, economist and neuroscientist. Older people are claimed to be better able to regulate their emotions, i.e. controlling for their anger, making more economically rational decisions and better at conflict resolution. To study the impact of life experience and age on cooperative decisions in a conflict situation, we recruited 44 young (age: 18 to 27 years), 32 middle aged group (age: 28 to 59 years) 48 elderly (age: 60 to 86 years old) participants. Participants were randomly paired within an age group and played the Prisoner's Dilemma Game (PDG) multiple times with each other, or with a computer. Across blocks the games were played in three environmental (emotional) contexts (negative: randomly losing money, positive: randomly winning money, and baseline environment). Overall young were the least cooperative in comparison to middle-aged and elderly subjects. All participants cooperated more when they played against another human than when they played against a computer but this differential effect was smallest in the elderly, when compared with middle-aged and young. Incurring random monetary losses (relative to winning or baseline blocks) encouraged all participants to cooperate more, as well as increasing cooperative potential (cooperating after being defected). Interestingly, young (relative to middle-age and elderly)

participants were most affected by the environmental (emotional) manipulation. The amount of net money earned reflected the cooperation pattern, with participants making more money when playing with human, and in a negative environment. Our finding shows that cooperative behaviour follows a similar pattern across the lifespan. But young subjects were more susceptible to environmental manipulations, especially in a social context, while elderly decisions were less affected by their opponent and were similar whether they were playing against a human or computer. We conclude that with increased age changes in the environment have a weaker impact on overall cooperative decisions.

2-G-18 How the sequence of interaction affects strategic choices and value encoding

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While strategic interactions and social influence were widely examined, less is however studied on how the sequence of play will impact players' strategic choices. We use functional magnetic resonance imaging (fMRI) experiments to investigate how individuals interact in a specific (Bayesian) type of poker game, which is similar to how athletes compete in pole vaulting, high jumping or weight lifting. Given their state of cards, 1, 2, 3, or 4, participants compete with appropriate card-picking. While each faces increasing chance of success in their state, the one who succeeds with a higher card will win the prize. The same type of games were played between 34 pair of participants under simultaneous or sequential interactions to examine how their choices will be affected by their state (card) along with the sequence of the game as well as their value encoding. Behaviorally participants exhibit distinct choice patterns under different types of game. Unlike in simultaneous games where their strategies are monotone in their states, participants tend to bluff when they have to be the first to reveal decisions especially in worse states. Comparably when they are the latter in making decisions, they are apparently influenced by the opponents' choices. Despite differences in task-relevant activations identified by pairwise contrasts, dissimilar neural representation of their state under distinct sequences of play echoes their behavioral disparities. Stronger BOLD activations are found to covary with better states in dorsal caudate, midbrain, anterior insula and dorsal anterior cingulate cortex only under simultaneous plays. Alternatively, these correlations no longer exist in trials when participants make sequential choices regardless of the order. Nevertheless, similar links are identified between their relative state and BOLD activities in caudate when participants move the last in sequence. In addition, stronger BOLD activities also appear in superior frontal gyrus when participants bluff compared to when they do not.

H – Individual & Lifespan Differences

2-H-19 Dopamine and differential susceptibility of cue-induced choice to environment: Evidence from psychological and genetic markers on children food behavior.

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The differential susceptibility model of dopamine signaling effects on environment responsiveness states that the association between a given genetic variant and the choice outcome in different contexts vary as a function of their adaptive quality (i.e., hypofunctional dopamine associated with poorer than average outcome in maladaptive contexts and greater than average performance in supportive environments). We first review basic neurobiological, behavioral and social mechanisms for differential susceptibility. Second, we discuss the generalizability of supportive evidence accumulated on the lifespan effect of early life environment on diverse cognitive and emotional decision making domains to cue-induced lifestyle behavior performed in diverse and changing real world contexts, with a focus on

food choice. We report three sets of empirical results from two child samples that provide partial support for the differential susceptibility effect of dopamine signaling on the adaptiveness of food choice and body weight consequences. Dopamine signaling was indexed by single-gene difference on DRD4 7-repeat (Study 1 and Study 3), multiloci gene difference (TaqIA-A1 allele, DRD2-141C Ins/Ins, DRD4 7-repeat, DAT1-10-repeat, Met/Met-COMT; Study 2), and psychological marker (external eating; Study 3). Environmental contexts examined are: fetal conditions (as indexed by birth weight; Study 2), living socioeconomic conditions (Study 1), food environment (Study 3). Outcomes are: eating under control experimental condition (Study 2), everyday eating (Study 1) and body weight consequences (as index in BMI Study 3). In support of the differential susceptibility hypothesis, we found for instance in Study 1 that children who are carriers of 7-repeat allele on DRD4 eat more fat than the sample average of their socioeconomic living conditions if they are in low SES, but less fat than average if they live in high SES. We also found in Study 3 that the BMI of carriers of the 7-repeat alleles were sensitive to environmental differences in obesogenic quality of the food environment whereas BMI of noncarriers was insensitive to this contextual difference. We discuss future disciplinary and interdisciplinary basic and translation research need and implication for individual and society.

2-H-20 Developmental changes in the influence of emotional interference on perceptual decision-making in borderline personality

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Emotion dysregulation is a core area of impairment in borderline personality disorder (BPD; Linehan, 1993; Lieb et al., 2004), marked by rapid changes in emotion, often in response to interpersonal events. To understand the basis of emotion dysregulation in BPD, previous experimental research has examined emotion perception using affect identification and interference paradigms (Domes et al., 2006; Fertuck et al., 2009; Daros et al., 2013). Nevertheless, prior research has not examined these emotion processing changes during adolescence, an age of vulnerability for the onset of BPD. In this study, 92 participants (50 with BPD symptoms, 42 matched controls) between the ages of 13 and 30 participated in an emotional interference task in which the goal was to identify the emotion of a face and inhibit an overlying emotion word. Participants completed 144 trials across 6 different conditions. In half of the conditions, the face emotion and word emotion were congruent. The three different target emotions for the conditions were angry, fear, and happy. To characterize developmental and clinical differences in decision processes, we modeled response time and accuracy using hierarchical drift diffusion modeling (HDDM; Wiecki, Sofer & Frank, 2013). We found that age was associated with faster evidence accumulation across conditions. The BPD group accumulated information slower than controls in the congruent happy condition and faster than controls in the congruent fear condition. On the other hand, neither age nor BPD status were significantly associated with differences in decision threshold. This set of results suggests that observed differences between emotion processing in BPD patients do not reflect impulsive responses driven by lower decision thresholds but rather altered attention to emotional stimuli. This is one of the first studies to explore the influence of emotion on decisions using a formal process model of speed-accuracy tradeoffs, extending previous findings of hyper-attunement to negative emotions in BPD. Taken together, these results indicate age exacerbates the tendency for the BPD patients to perceive social threats. Building on previous research examining neural correlates of DDM, we hypothesize that activation of the salience network to emotional stimuli increases as individuals with BPD get older.

I – Intertemporal Decision-Making & Self Control

2-I-21 Search strategy and delay discounting: evidence for flexibility

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Objective: A large amount of research has uncovered patterns of information acquisition in multi-attribute decisions. Reeck, Wall, and Johnson recently report that search patterns on delayed rewards are causally linked to apparent preferences. Here, we study a different intertemporal choice task in which (1) each option presents a pair of delayed payoffs and (2) payoffs (rather than delays) vary between trials. In this setting, we further examine the weighting of payoffs and choices associated with particular search styles. Lastly, we determine the relationship between search strategy, decision variables, and choice at the trial-by-trial level. Methods: Subjects (N = 26) completed a binary choice task while their eye movements were recorded. Subjects were presented with a series of choices in which each option promised two rewards: one that was occurring sooner in time and one that occurring at a later date. Payoff information was presented at four quadrants of the screen. The timing of these payoffs was held constant but the payoffs associated with each choice differed across trials. For instance, option A may promise $X in 1 day along with $Y in 30 days; option B then provides $A in 1 day and with $B in 30 days. We designed the trials such that on the majority of the trials (64%), the inequalities X < A but X+Y > A + B (and vice versa) would hold. One randomly chosen trial was actualized for each subject's payment. Results: To summarize search strategy on each trial, the Payne Index (PI) was computed as the relative difference between comparative and integrative gaze transitions. PI was reliably measured within subjects (Cronbach's alpha = 0.99). K-means clustering on transitions and choice suggests a 2-cluster solution. Integrative searchers were associated with more patient behavior, longer gaze duration, slower saccade velocities and slower reaction times. At a trial-by-trial level, a multiple regression on choice reveals significant influences of decision variables (e.g., payoffs and delays) as well as search variables (e.g., gaze duration and transitions). Conclusions: We firstly replicate an apparent duality in aggregate search and discounting behavior. Secondly, we observe that the relation between search strategy and apparent preferences are the opposite of those previously reported (and thus seemingly task-dependent). In the present study, integrative searchers discount, consider, and choose more slowly than comparators. The increased prevalence of comparators in our longer delay condition suggests that ease of integration is affected by the values of attributes under consideration. Within-subject variability on the other hand, is largely contingent on the payoffs presented rather than variation in search during each trial.

2-I-22 The Habitization of Self-Control

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Objective: We face a consistent set of choices every day - what to eat, whether to exercise, how much to spend - for which self-control is required to satisfy long-term goals. As with other executive functions, self-control is generally considered to be an effortful process that is subject to occasional failure. We argue that choices made for regularly occurring decisions leads to the formation of habits, reducing the cost of maintaining a consistent level of self-control. We refer to this process as the habitization of self-control and test predictions of the hypothesis in an fMRI and a behavioral experiment. Methods: Participants completed an intertemporal choice task weekly for five weeks. We tested differences that relate to habit formation and the exertion of self-control between weeks one and five. In two studies, we (1) examined the behavioral effects of habit formation on participants' discount rates as well as their sensitivity to framing effects, and (2) analyzed the neural correlates of habit formation in intertemporal

choice. Results: One consequence of habit formation is that it renders behavior less susceptible to contextual variables that may otherwise bias choice. In study 1 (N=20), we estimated the size of an intertemporal choice framing effect, the date-delay effect (Read et al., 2005), on weeks one and five of the study. We found that habitization reduced the size of the date-delay effect (p0<.05). Several studies have related activity in fronto-parietal cortex to the exertion of self-control. We tested whether the recruitment of fronto-parietal cortex is reduced with habit formation in study 2. fMRI BOLD data were acquired on weeks one and five as participants completed the intertemporal choice task. For both weeks one and five, activity in brain reward areas (ventromedial prefrontal cortex, ventral striatum, and posterior cingulate cortex) was correlated with subjective value. However, dorsolateral prefrontal cortex (dlPFC) activity was negatively correlated with subjective value on week one and this correlation was significantly reduced by week five. By contrast, activity in the dorsal striatum showed increasing correlation with subjective value across sessions. We conclude that habit formation is associated with a shift in the neural locus of delay discounting from the dlPFC to the dorsal striatum. Conclusions: Habit formation in intertemporal choice has two positive effects. First, it decreases susceptibility to contextual variables that otherwise bias preferences. Second, habits permit consistent rates of delay discounting to be expressed even as behavior depends less on brain areas associated with cognitive control (dlPFC) and more on brain areas associated with automatic action selection (dorsal striatum).

2-I-23 Time-driven reassessment of anticipated reward magnitude

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Introduction: Waiting patiently for a future reward is not always advantageous. Previous research has shown that, in uncertain, dynamic environments, decision makers can learn that time elapsed is either a positive or negative predictor of delay time remaining. Here we examined environments in which an outcome's delay covaried with its magnitude. Decision makers could infer, based on the passage of time, whether the awaited outcome would likely be favorable or unfavorable. We examined whether participants could calibrate their willingness to wait on this basis, and whether they could flexibly recalibrate when the environment changed. Methods: Participants (n = 40) performed a willingness-to-wait task with two different reward/delay distribution conditions. Each trial randomly delivered either an 8-cent gain or a 1-cent loss, at a random delay. In the Rising Value condition, losses tended to arrive earlier than gains. A long elapsed delay therefore supported an inference that the current trial would be a gain, and the best strategy was to be highly persistent. In the Falling Value condition, gains tended to arrive earlier than losses, and the best strategy was to quit if the delay lasted more than about 5 seconds. Each participant performed four 10-minute blocks of the task, alternating between the two environments in counterbalanced order. Results: Decision makers were sensitive to the environment-specific patterns of covariation between reward magnitude and delay. In within-participant comparisons, participants were willing to wait longer for rewards in the Rising Value condition than the Falling Value condition, qualitatively in line with the optimal strategy. Willingness to wait also varied across individuals, and was positively correlated between the two environments. As expected, longer waiting times were associated with higher total earnings in the Rising Value condition, and lower total earnings in the Falling Value condition. Conclusion: Our results build upon previous demonstrations that decision makers can adapt their delay tolerance advantageously to maximize rewards. The present findings imply that adaptive calibration of persistence takes into account the covariance between two attributes (here, magnitude and delay). The results also show that adaptive calibration still holds in the presence of potential losses. Finally, our results show that people can flexibly adapt to unsignaled change in the

statistical structure of the environment, and provide helpful new data for understanding the learning dynamics that support this ability.

2-I-24 Greater activity in vlPFC during positive emotion regulation is associated with better dietary self-control

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Objective: Longitudinal studies have associated aggregate measures of self-regulation with desirable life outcomes such as good health, economic prosperity and social connectedness. However, we do not yet know if and how regulatory abilities transfer across domains. Therefore, we combined emotion regulation and dietary choice tasks together with fMRI to investigate behavioral and neural links between regulatory success across the two domains. Methods: 32 healthy participants (18 women; mean age = 22 years, mean BMI = 21.5) completed previously established emotion reappraisal and dietary self-control tasks in a cross-balanced order. In the emotion task, participants either viewed standardized positive and negative photos without altering their feelings, or reappraised their feelings so that the emotion became weaker. In the dietary choice task, participants chose whether to eat A) the currently shown item, or B) nothing at the end of the study. Dietary self-control success was measured as the proportion of trials in which the participant used self-control. Emotion reappraisal success was measured as the difference between emotion ratings just after reappraising the image and post-scan ratings after viewing the same picture again without reappraisal. Results: Behaviorally, there was no significant correlation between emotion regulation and dietary self-control in the positive ($r = 0.07$, $p = 0.7$) or negative domains ($r = -0.15$, $p = 0.41$). At the neural level, however, we found that greater activity in the left ventrolateral prefrontal cortex (vlPFC) when attempting to regulate positive emotions was associated with better dietary self-control ($T = 7.92$, $p = 0.01$, whole-brain FWE corrected). In general, large portions of left ventro- and dorsolateral PFC were more active when successfully regulating positive emotions. There was no association between brain activity during negative emotion regulation and dietary self-control. Conclusions: These results are in line with prior findings showing that vlPFC is involved in emotion regulation. Moreover, the relationship with dietary self-control success hints at a possible overlap in mechanisms involved in dampening positive emotional reactions to pictures and appetitive foods. This is consistent with the proposed "brake" function of vlPFC (e.g. Aron et al. 2004; 2014), and suggests that vlPFC helps to stop or suppress both physical and cognitive responses.
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2-I-25 Homeostatic State and Intertemporal Choice: Choice, RT and Diffusion Model Differences due to Experimental Hunger Manipulation

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Objective: Recent evidence suggests that homeostatic drives, specifically hunger, may affect self-control, reward valuation and intertemporal choice preferences, even outside the domain of feeding. We sought to extend the behavioral literature by investigating reaction time effects and associated computational models compatible with biological processes. Methods: Nineteen subjects completed two experimental visits, arriving following a 12 hour fast. On one visit, subjects remained fasted, whereas the other visit subjects ate until they felt "comfortably full". Participants completed 160 adaptive intertemporal choices during fMRI. Homoeostatic state RT differences were evaluated using hierarchical Bayesian models via the BAMBI module. Feeding's effects on intertemporal choice were investigated via generalized linear mixed effects logistic regression. Finally, RT data was fit as a hierarchical drift-diffusion model via the HDDM package in python. fMRI analysis are ongoing utilizing FSL through the nipy Python package.

Results: Relative to hunger, participants in satiety exhibited greater stochasticity, as evidenced by the significant model-improvement of including the interaction between offered indifference point and homeostatic condition (2=8.7166, DF=1, p=0.0032), though there was not a general main effect of homeostatic condition on estimated discounting steepness (mean=-0.347, hpd=-0.784-0.093). There was a significant main effect of experimental condition on RT (mean=0.1371, hpd=0.0983-0.1756). Feeding slowed RT by an average of 0.137 seconds when compared to Fasting (mean=2.524 seconds, hpd=2.281-2.7533). Following up on this effect, 9 potential models were fit and compared using the HDDM package in python. Results indicated that the best fitting model allowed hunger-based changes in both non-decision time (t parameter) and decision threshold (a parameter) (DIC=13650.18, nearest alternative model DIC=13666.4). Parameter inference using our best-fitting model indicated that there is a 90.09% chance that the t parameter differs due to hunger condition, whereas there is a 71.6% chance that the a parameter differs due to hunger condition. Conclusions: Relative to satiety, intertemporal choice performance in deprivation was enhanced both in terms of accuracy (reduced stochasticity) and increased speed (lower RT). The best fitting HDDM model indicates that this may be due to hunger-based changes in the t and a parameters, a novel finding in the literature. Future works should follow-up on these findings and determine whether these RT differences apply simply to intertemporal choices, or if this is a broader effect of the homeostatic influences of hunger on the decision-making process and how this interacts with decision-making neural networks.

2-I-26 Sunk cost effects appear similar in parallel neuroeconomic foraging tasks in mice, rats, and humans

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Sunk costs occur when decisions are based on expended costs rather than future expectations. We developed a neuroeconomic foraging task for mice, rats, and humans. Rodents foraged for food and humans for internet videos in a repeated serial choice task. Mice were trained to run around a square maze with four feeding sites, each providing a distinct flavor (restaurants), with two distinct zones: an offer zone and a wait zone. On encountering each restaurant, mice entered the offer zone and a tone sounded whose pitch indicated a delay (random, 1-30 s). Mice could enter the wait zone and wait out the delay for food or leave the offer zone for the next restaurant, thus skipping the offer. Delay was indicated on entry into the offer zone, but did not start counting down until entry into the wait zone. If mice left the offer zone for the next restaurant (skip) or changed their minds after entering the wait zone (quit), the offer was rescinded and the tone ceased. Importantly, mice had 1hr to forage for their food for the day, making this an economic task on which the mice had to budget their time. Rats also foraged for food on a maze with four restaurants each delivering a different flavor of food (Steiner and Redish, 2014). Humans foraged for short videos in four galleries, each delivering a different "flavor" of video (Abram, MacDonald, Redish, 2016). In the rat and human versions of the task, there was no separate offer zone, but rats and humans tended to make skip decisions quickly (rats <4s, humans <2s), suggesting that they were also making decisions in two stages. All three species revealed stable preferences across the different flavors that varied from individual to individual but were consistent across trials within an individual. In mice, the time spent within the offer zone deciding to accept or skip did not influence the likelihood of quitting in the wait zone despite detracting from the 1hr budget. However, time spent in the wait zone decreased the likelihood of quitting compared to offers with equivalent delay remaining yet with less prior time invested. Rats and humans showed similar effects: time spent during the decision-time (<4s rats, <2s humans) did not affect likelihood of quitting, but time invested beyond that decreased

the likelihood of quitting, even for equivalent remaining delays. These data suggest that time spent deciding between competing options are not counted towards sunk costs. These findings suggest that sensitivity to sunk cost cannot be fully explained by social factors nor actual resource depletion but rather points to a decision-making vulnerability in the face of impending rewards.

2-I-27 Economic analysis of adolescents' and young adults' decision-making in private versus when observed

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Decisions made during adolescence and young adulthood have economic impact on people throughout their lives. It is now clear that teens and young adults more often than midlife adults make decisions that impair their own educational, health, and social outcomes, and their financial outcomes in the form of foregone future salary and retirement. Reckless behaviors come at a substantial financial burden to the society that bears the costs of hospitalization, preventive policies, and educational campaigns. The decisions that adolescents and young adults face such as whether to smoke, whether to have unprotected sex, and how much time to devote to studying are an outcome of complex interactions of an array of individual decision-making parameters; these include attitudes towards known and unknown risks, time preference, and the relative valuation of equally sized gains and losses. Importantly, most decisions, particularly in adolescence, are made not privately but in a social context. The presence of peers is often considered as the culprit in reckless behaviors. We designed a series of behavioral studies to disentangle whether adolescents? and young adults? risk attitudes, ambiguity attitudes, time preference or loss aversion are affected by the presence of peers. To date, 600 participants aged 12-25 years old participated in these behavioral studies. Each participant made a series of incentive compatible choices over risky and ambiguous gambles and between options that involve sooner smaller or later larger payments. We used three reward types: money, healthy and unhealthy food. Participants made choices in private and when observed by a peer. Our results suggest that common belief that adolescents and young adults become more risk taking in the presence of peers may be wrong if we define risk attitudes as in economic theory. Instead, young adult?s and adolescent?s time preferences seem to be affected by observation. We discuss how the effects differ for different reward types.

2-I-28 The Effects of Bariatric Surgery on Delay Discounting Modeling in Obesity

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Goal: We investigate in two studies if bariatric surgery impacts patients' self-control abilities that may contribute to the success of this weight loss procedure beyond changing the digestive tract. We build upon research that found self-control and delay discounting differences between the lean and obese participants. We also investigate domain specificity of these differences by comparing impatience for food with those for money. Methods: Obese (N=74) and lean (N=40) participants first performed an intertemporal indifference point task for money and food rewards. The obese were recruited from a patient population qualifying for bariatric surgery and were seen before surgery and twice afterward (i.e., 3 & 12 months). Lean controls repeated the task 6 months later. Lean (N=45) and obese (N=17, from the same population) patients then completed a non-hypothetical, delay-discounting task consisting of choosing between smaller-sooner and larger-later rewards for money and food rewards. Both groups repeated the task 6 months later, the obese patients after bariatric surgery procedure. Results: Study 1:

Pre-surgery obese patients needed significantly more candies to wait one week compared to lean (m_obese=16.3 (SE=2.79)<m_lean=9.84 (SE=1.18), t=2.13, [0.45, 12.5]). We found no such differences for money (m_obese=5.60 (SE=0.35)<m_lean=6 (SE=0.25), t=1.12, [-1.09,0.30]). Differences in indifference points 12 months post-surgery for food between lean and obese reduced (m_obese=12.2 (SE=2.61)>m_lean=11.9 (SE=2.02), t=0.098, [-6.27, 6.92]). Study 2: We estimated the ASAP delay discounting model as best fitting our data and compared differences in discount parameters between groups and over time. Pre-surgery obese patients were again more impatient for food than lean controls (k_obese=0.0028 (SE=0.009)<k_lean=0.026 (SE=0.02), t=2.39, [0.004, 0.046]). Post-surgery differences between groups again reduced (k_obese=0.024 (SE=0.008) > k_lean=0.012 (SE=0.003), t=0.18,[-0.027, 0.002]). No differences were found for money (k_obese=0.018 (SE=0.007)>k_lean=0.015 (SE=0.003), t=0.67, [-0.015, 0.009]). Conclusion: We provide novel evidence that differences in self-control for food but not money between lean and morbidly obese patients reduce post-bariatric surgery. We show such differences in self-control are food-specific and do not extend to other rewards like money. We now investigate if biological factors could explain the observed differences in behavior. We are currently examining the relationships with metabolic and inflammatory markers (i.e., adipokines and gut bacteria richness known to change after bariatric surgery) and scanned participants' brains with fMRI (study 2). We hope results by the conference will include mediating effects of these measures.

J – Learning & Memory

2-J-29 Noise or Signal? Context-sensitive neural signals that discriminate the source of errors during adaptive learning

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Objective: Learning is driven by discrepancies between new evidence and prior beliefs. Previous work has identified neural mechanisms of error-driven learning, most prominently in the dorsomedial frontal cortex (DMFC). However, adaptive learning requires not just detecting errors but also determining their source. Errors that come from irreducible noise in the environment should be ignored, while errors that reflect an underlying change in environment should lead to belief updating. Here we investigate the neural mechanisms involved in discriminating different sources of error. Methods: Seventeen participants performed a predictive inference task in an MRI scanner. In this task, participants were asked to saccade to one of ten targets in a circular array. Across two conditions, we dissociated the source of potential errors. In the "unstable" condition, the best target was always rewarded, but its location changed frequently. In the "noisy" condition, the best target changed only occasionally, but was only rewarded probabilistically. Results: Participants' behavior was appropriately sensitive to the context. In the unstable condition, participants always responded to errors, regardless of magnitude, and immediately updated their choice on the subsequent trial. In the noisy condition, participants only responded immediately to large errors that could not be due to noise; information about small errors was integrated across trials and lead to behavioral shifts only after a consistent history. In fMRI, DMFC and PPC not only showed greater activity for errors, but also tracked error magnitudes, particularly in the noisy condition where error magnitude was informative. Activity in DMFC and PPC also reflected errors on previous trials in addition to the current one. Finally, the multivoxel pattern in DMFC discriminated between stay and switch behavior for small errors in the noisy condition (where stay versus switch depended on more than just error magnitude). Conclusions: People were able to learn and respond appropriately to errors in different contexts, updating their behavior when errors reliably signaled an environmental change and integrating feedback across trials when errors could reflect irreducible noise in the environment. DMFC tracked error-related signals in a context-sensitive way, appropriately combing

information about error magnitude and error history and predicting behavior on the next trial. This further supports a role for the DMFC, which has long been linked to error-driven learning, not only in responding to errors, but also in discriminating the source of errors and adjusting behavior in an adaptive manner depending on that source.

2-J-30 Neurocomputational Dynamics of Sequence Learning

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Objective: One of the big questions of reward learning is how the brain updates the structure of the decision environment (i.e. a model or a mental map). Previous research in this area has primarily focused on stochastic transition models, and little is known about the computational mechanisms of deterministic process learning such as learning of patterns in sequences of states. Given a repeated pattern in a sequence, individuals can learn the sequence much faster than standard transition matrix models predict. Here we use a simple modified Serial Response Time (SRT) task to demonstrate that this behavior can be explained by a two-level Bayesian updating model that assumes prior beliefs about types of structures, or patterns, and use fMRI to identify the brain networks that track these beliefs. Methods: 24 human subjects observed 50 sequences of images in a 3T Siemens fMRI scanner, with 12 images per sequence and 3 image types (a hand, a landscape, and a face). We instructed subjects to respond to each type with a corresponding button and incentivized their accuracy and response time (RT). 30 sequences had repeating patterns of length 2 to 6, and the rest were preselected to display no obvious patterns. To predict subjects' RTs, we used a two-level Bayesian model that assumes a prior space of possible patterns and updates beliefs about specific patterns and predicted state (i.e. images). We used the model to calculate entropy as a measure of uncertainty and applied GLM and ROI analyses to identify brain regions correlated with the model variables. Results: We observed that subjects responded faster to the images in sequences with repeating patterns, with RT decreasing rapidly as the sequence progressed. Our behavioral model was able to explain both differences in RTs between the two conditions (patterns and non-patterns), and to quantify the rate at which RTs were decreasing in the pattern condition. We also identified the brain networks that reflect the dynamics of the model variables, including the intraparietal sulcus (IPS), the ventral prefrontal cortex (vPFC), the hippocampus, and the anterior cingulate cortex (ACC). Conclusions: Here we sought to explain fast learning of patterns in a simple sequence prediction task. We showed that subjects' beliefs, represented by response times, are best explained by a two-level Bayesian updating model that tracks uncertainty about the state of the world and the structure of the sequence. These predictions were qualitatively and quantitatively better than those of competing models such as the conditional state-state transition matrix. Focusing mostly on regions that have been identified in other sequence learning tasks, we provide a detailed model-based account of sequence learning in the human brain.

K - Methods

2-K-32 Bayesian Optimal Sequential Inference for Experiments

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We propose a complete inference method for experiments combining the advantages of Sequential Monte Carlo and Bayesian Optimal Design. The method performs inference in real time and uses the subject's previous answers to compute an optimal next question. A broad range of optimality criteria can be used, including maximizing information about model parameters, prediction accuracy or indifference sets recovery. The method expends and generalizes recent work done in the domain of optimal design by making it non-model-specific, compatible with continuous parameter space or model selection, and not

relying on approximations. We further propose a strategy to maintain randomness in the questions design when needed. This method can be particularly useful to shorten length of experiments while improving accuracy. Multiple examples are provided to illustrate performance.

2-K-33 The Use of Single Nucleotide Polymorphs of Neurotransmitter Transporter Genes to Address the Problems of Internal Validity and Identification in Regression Discontinuity Design Modeling

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The gold standard for experimental research is the controlled experiment, where each participant is randomly assigned to either a treatment or control group. The experimenter then manipulates one variable and controls the other variables through randomization. The regression discontinuity model arises when assignment to a treatment group is not randomized, but is a discontinuous function of an underlying variable. Therefore the internal validity of the experiment is called into question, as the possibility exists that the underlying variable is driving the experimental results rather than the treatment. A classic example of the regression discontinuity design occurs in college. On average, students who receive a full tuition scholarship earn a higher grade point average than students who receive no scholarships while attending college. But if the cumulative GPA earned during high school meeting a certain benchmark is the requirement to earn a scholarship, then to conclude that a scholarship earned while attending college is the variable that causes one's cumulative college GPA would be erroneous. The underlying issue the model is attempting to address is the problem of endogeneity. In the absence of either instrumental variables or exogenous variables, valid parameter identification is not possible. Thus in the search for valid instrumental or exogenous variables, traditionally, several candidates have been used. Often used indicators of success in college include high school GPA and ACT scores. The difficulty with using these indicators as explanatory variables is that they produce valid, yet unsatisfactory results. The same underlying factors or constructs that drive high school GPA also drive college GPA. Therefore, the purpose of this study is to investigate a new approach to better understand factors that contribute to divergences in human performance. Particularly, we investigate the role single nucleotide polymorphs (SNIP's) in neurotransporter genes play in both cognitive function and the outward manifestations of human performance. Given the role Serotonin plays in cognitive function, and also the roles both serotonin and dopamine play in self-efficacy, in particular, we suggest using polymorphs of: Serotonin transporter protein (SLC6A4), and Dopamine transporter (SLC6A3) in order to investigate the role variations of these genes play in explaining differences in human performance. If successful, these SNIP's may become useful exogenous variables for identification within Regression Discontinuity Design Models.

2-L-34 Confidence in Risky Value-based Choice

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Our decisions are based on a comparison between the subjective values associated with the options we face. At the same time, the subjective confidence we report when making choices appears to carry information about the value comparison (De Martino, Fleming, Garrett, & Dolan, 2013). While a large body of work has investigated the role of confidence in perceptual decision-making as well as value-based decisions under certainty, little work has investigated the interplay between subjective value (SV), confidence, and reaction time (RT) in risky decision-making. Accordingly, we sought to characterize the effects of risk level on confidence and its relationship to SV and RT, in the context of value-based choice. Participants (N = 300) were recruited for an online task which involved a series of choices between a

certain and a risky option, rating their subjective confidence after each choice. To ensure that the differences between the chosen values (i.e. the difference in SV between the two options at hand) sampled a wide range and were centered around zero, we first assessed each participant's risk sensitivity in a preliminary calibration experiment. After this calibration phase, payoff magnitudes were tailored on an individual level, based on the participant's choice behaviour in the first phase and according to estimated best-fit parameters of a simple prospect-theory model. Jointly analyzing choices (risky versus sure), SV of the chosen option, confidence, and RT, we found a confidence 'cost' when the risky action is chosen, such that participants reported significantly lower subjective confidence when choosing a risky versus certain option. Further analyses demonstrate that opting for a risky choice significantly diminishes the strength (i.e. slope) of the relationship between subjective confidence and RT when compared to trials where the gamble was foregone--that is, the longer the RT, the lower the confidence. Similar effects of risky choice were observed on the relationship between subjective confidence and SV. Likewise, our analyses revealed that risk also significantly weakens the well-documented effect of SV of the chosen action upon RT: the larger the SV difference, the faster the RT. Finally, preliminary results suggest that risk has an effect on the relationship between confidence and one's sensitivity to SV. Taken together, these results suggest that risky choice (in comparison to choice under certainty) attenuates both overall confidence and the previously observed relationships between value and decision time, value and subjective confidence, and decision time and subjective confidence.

2-L-35 Noradrenaline modulates decision urgency during sequential information gathering

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Objective: The arbitration between a timely decision and extended information gathering involves a non-trivial speed-accuracy tradeoff (Henmon, 1911; Martin and Müller, 1899). Sequential information gathering tasks are commonly used to investigate this arbitration; that it is impaired in psychiatric disorders such as schizophrenia or obsessive-compulsive disorder (Hauser et al., 2017; Moutoussis et al., 2011), suggests that its neurocognitive mechanisms merit better understanding. Methods: We investigated the role of dopamine and noradrenaline in a sequential information gathering task ("information sampling task" [IST]; Hauser et al., 2017) using a double-blind, placebo-controlled, between-subjects drug study. Three groups of 20 subjects each received either a noradrenaline beta-receptor antagonist (40mg propranolol), a dopamine D2/3 receptor blocker (400mg amisulpride) or a placebo. Subjects were allowed to gather as much information as they wanted before making a decision about which of two colours was more plentiful in a set of 25 hidden cards. We used a recently developed Bayesian computational model (Hauser et al., 2017) to investigate the cognitive processes driving this information gathering behaviour. Results: Noradrenaline blockade led to reduced information gathering, whether sampling was costly or cost-free. No effect was observed for dopamine blockade. Computational modelling suggested that subjects exhibited a subjective urgency to make a decision as sampling progressed; i.e., subjects applied progressively more liberal criteria or a collapsing bound on the evidence. This urgency increased in a non-linear manner and its onset varied across participants. We found that the noradrenaline group expressed a significantly earlier urgency onset than the placebo group. Conclusions: Our results show that noradrenaline plays a critical role in information gathering and that blocking noradrenaline leads to more impulsive responses due to an increased urgency to decide. Our findings thus provide important insight into the neurocognitive mechanisms of information gathering, which may also help better understand psychiatric disorders that show impairments in information gathering.

L - Risk & Uncertainty

2-L-36 Medical Decision Making under Uncertainty: Behavior and Neural Correlates

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Objective: Uncertainty is ubiquitous in real-life decisions, and individual attitudes towards it often influence the ability to reach optimal decisions under critical situations. Previous neuroimaging studies of decision making under uncertainty mostly focused on the monetary domain. Although a few studies looked at other rewards (e.g. food, water), the neural basis of decision making in more complex and abstract domains is not well characterized. Choosing medical treatment is one of the most important decisions we make and involves high level of uncertainty. In this study, we aim to investigate individual attitudes towards uncertainty in medical decisions and their neural basis. Methods: 16 human participants (ages 29.5±7.9, 9 females) made medical and monetary decisions in a functional MRI experiment. In the medical task, participants were asked to imagine that they were injured and lost the motor function of their legs. On each trial, participants chose between a fixed treatment with a certain outcome of slight improvement, and an experimental treatment with chance of better improvement but also chance of no effect. The experimental treatment varied in the degree of improvement it offered, and in the level of uncertainty. In the monetary task, participants chose between a fixed monetary gain and a lottery with chance of a higher gain, but also chance of no gain. For both medical and monetary tasks, the outcome probability of the uncertain option was fully known in half of the trials (risky trials), but only partially known in the other half (ambiguous trials). Results: Behaviorally, attitudes towards risk and ambiguity were not correlated across participants either in the medical ($r = 0.047$, $p = 0.86$) or monetary ($r = 0.15$, $p = 0.57$) domains. Participants were averse to ambiguity in both domains ($p < 0.01$ in medical domain, $p < 0.05$ in monetary domain, two-tailed, one sample t test). The degree of aversion in the medical domain was correlated with that in the monetary domain ($r = 0.66$, $p < 0.01$) and the magnitudes of the two were not significantly different ($p = 0.28$, two-tailed, paired t test). A whole-brain analysis revealed higher activation in the right inferior temporal cortex and the parahippocampal gyrus during medical decisions compared to monetary decisions, potentially reflecting increased verbal and memory processing in the medical task. A parametric analysis using each participant's subjective ratings of the treatment outcome levels identified brain regions, which have been previously implicated in value representation, including a focus in the insula. Conclusions: These preliminary results suggest the existence of both domain-specific and domain-general neural mechanisms for valuation and decision making.

2-L-37 Transfer of confidence in a novel observational learning task

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Objective: Methods for measuring the confidence with which people make decisions, have traditionally relied on post-decision self-reports. We wanted to develop a new experimental paradigm that aims at measuring the confidence in a decision without participants having to explicitly rate their confidence, and then show transfer of confidence through observation using said paradigm. Methods: In our experiment, the participants have to move a cursor around a circle to catch particles that move from the centre to the edge of the circle. The direction of the particles are block-wise determined by a mean and a standard deviation from that mean. The participants can change the size of the catcher, and the amount of points rewarded for each catch is inversely proportional to the size of the catcher. The paradigm was tested in several deceit-free behavioural psychophysics experiments and analysed using computational modelling. Results and conclusions: To test that the task really measures confidence, we added a

condition in which blocks of trials were followed by a confidence rating scale. The model estimated trial-by-trial particle variance correlated strongly with the normalized ratings given by the participants. Similarly, the computational modelling found that each participant's trial-by-trial estimation of the particle variance to be correlated with the width of the cursor on the given trial. We also added a condition with more feedback uncertainty, and found that the overall confidence was systematically lowered as a result. Finally, to investigate if it is possible to transfer confidence between participants, we ran an experiment where participants could observe the cursor width (but not the position) chosen by one of two previous participants; one high confident, one low confident. Results show that participants that observed a player with higher base confidence chose a significantly smaller catcher than the group observing a player with lower base confidence, an effect that persisted after the other player's choices were no longer displayed. This shows that the confidence the participants had in their choices was altered beyond that of strict observational mimicry. In conclusion, we have developed a novel task that allows for measuring choice confidence implicitly, and used this task to show that participants adapt an observed level of confidence to their own choices, a level that persists even after observations are no longer available.

2-L-38 Risk for self versus risk for others: social proximity shapes the degree of loss aversion

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Taking risk is ubiquitous in our daily life and has been a focus of research in economics, management science and psychology for decades. Empirical studies reveal that individuals generally exhibit loss aversion, namely, that the experience of a loss tends to exert a greater hedonic impact than gain of the same magnitude. Recently, vicarious risk taking involving others has received increasing attention in economics as well as psychology. Yet, few studies have investigated the extent to which proximity among individuals may modulate their degrees of risk aversion and loss aversion. We address this question in two behavioral experiments. Subjects are instructed to make risky choices for themselves, their closest friends as well as unacquainted counterparts either under only the mixed condition or across gain, mixed and loss conditions. We find that subjects exhibit a significant tendency of loss aversion regardless of whether the financial outcome is egocentric or allocentric. Intriguingly, we observe a diminished degree of loss aversion in taking risk on behalf of unfamiliar individuals with farther social distances than for themselves or close friends. A neuroimaging experiment in-progress is expected to enable further disentangling the neuroscientific foundation of such a process. We anticipate that the combined behavioral and neuroimaging data, extending previous findings for the empathic responses to vicarious financial gains and losses, will support the view that the reduced degree of loss aversion is shaped by an attenuated emotional involvement with unfamiliar individuals.

2-L-39 Token asset effect on monkey's decision making involving risky gains and losses

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Normative economic theories of decisions under risk postulate that: humans evaluate the outcomes of decisions as gains or losses relative to their current wealth level and show different risk-attitude when facing risky gains or losses. However, the neural mechanisms underlying these effects are not known. To investigate these questions, we designed a risk-based decision making task, in which monkeys choose between a sure option with certain outcome and a gambling option with uncertain outcome with different explicitly indicated probabilities. Critically, the monkeys were trained to accept token as a secondary reinforcer. Across multiple trials, they had to accumulate six tokens to earn a fluid reward. This allowed us to test gamble options resulted in a gain or a loss of token. In the token task, the

monkeys could estimate subjective value (SV) of options based on the relative change in token number or on the resulting absolute token number. Behaviorally, the monkeys showed an overall tendency of risk-seeking in both gain and loss domain. However, they displayed more preference for the gamble option when facing a risky gain than when facing a risky loss. This is opposite of the typical risk preferences found in human studies. In addition, the number of token a monkey owned at the start of trial influenced its choice behavior, in particular in the gain domain. With increasing token assets, monkeys were prone to choose the gamble option less often in the gain domain, but more or equally often in the loss domain. Next, we tested models in the absolute and the relative framework. In an absolute framework, the estimation of SV of option is independent of whether the relative change of tokens represents a gain or a loss. Instead, SV solely depends on the number of token the monkey will have at the end of each trial. Such an absolute SV model did not fit the behavioral data well. In the relative framework, we fitted several utility models that were variants of prospect theory model. In these, we allowed token asset to modulate one of the three parameters in prospect theory: risk-attitude (α), loss aversion (λ), probability weighting (γ), as well as bias and slope of the choice function. In the gain domain, the best-fitting model was the one in which increasing numbers of starting tokens reduced risk-attitude (i.e., α was shifted in a negative direction). This is consistent with the behavioral data that monkeys become less risk-seeking with increasing token assets. However, taking the starting tokens into account did not significantly improve fitting in the loss domain. Altogether, our behavioral findings indicate the monkey's choices depend on relative changes in wealth as well as the number of tokens the monkey owns at the end of the trial.

M - Social Rewards & Social Preferences

2-M-40 Power Reduces Sensitivity To Immediate Reward And Enhances Learning During Social Exchange

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Power is pursued and admired by many individuals. However, how power is computed in the brain remains unknown. Here we addressed this question using neuroimaging, computational modeling, and a social exchange paradigm in which participants may change their partners' proposed monetary offers in the future. We showed that participants successfully increased future offers when given power. Computational modeling suggests that power reduced the behavioral dependency of choices on immediate offers, and neural responses to immediate reward outcomes in ventral striatal (VS). Power also enhanced neural encoding of social learning signals (i.e. prediction errors) in VS and ventromedial prefrontal cortex (vmPFC). Furthermore, activity and connectivity of VS, but not vmPFC, distinguished individuals who felt more empowered from those who felt less empowered. These results suggest that power and belief about power both reduce sensitivity to immediate outcome and enhance learning, a process encoded by corticostriatal circuits.

2-M-41 Social Distress Response in the Context of Empathy in Rats

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Introduction: Showing what is commonly referred to as prosocial behaviors is appreciated and rewarded in human society , whereas anti-social actions often lead to isolation and reclusion. How can we scrutinize the brain processes associated with behaviors involving the emotions of others? While neuroimaging can explore vicarious activations using correlational approaches, it cannot influence neuronal activity (hence limiting causality), and have a limited spatial resolution. Here, I present a rodent model of empathy-driven prosocial behavior, suited for cutting-edge neuroscientific manipulations,

which scrutinizes the response to other's distress in the form of prosocial (help) or anti-social behaviors (aggression). Methods: In a modified operant conditioning box, rats first developed a preference for a higher value option in a binary choice situation. In a second time, choosing that option led to a punishment to an adjacent conspecific. Accordingly, if other's distress carries a negative value for some individuals (prosocial) but not for others (aggressors), the first group should switch preference while the second should stick with the higher value option. Results: We found that a subset of animals switched their previously acquired preference for the higher value, to the lesser value option, upon association of the former with a conspecific's distress. This effect was robust and likely modulated by the distress intensity experienced by the conspecific. Conclusion: This behavioral paradigm provides mean to scrutinize both pro- and anti-social behaviors. Indeed, while the first group allows examining how the perception of other's distress promotes pro-social behavior, the second group enables the exploration what predisposes some individuals to disregard the distress of others

2-M-42 Hyper-prosocial responses in subjects four decades after high quality early childhood investment

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Objective: We tested the possible impact of early childhood interventions on social decision making and prosociality. Methods: We recalled intervention and control subjects from one of the world's oldest randomized control studies of early childhood investment-the Carolina Abecedarian Project (ABC)-and had them play an ultimatum game, a well-validated social exchange game, during functional magnetic resonance imaging. We measured the behavioral and neural reactions to disadvantageous, equal, and advantageous ultimatum game offers Results: We report a dramatic prosocial response in an ultimatum game in participants given high quality educational intervention 44-45 years ago. The group that received intervention displayed symmetric inequality aversion on an ultimatum game based on the dominant Fehr-Schmidt model of social fairness. Furthermore, with a machine-learning approach, we show that we can classify if the participants were from the control or intervention group using their brain responses to unfairness during the ultimatum game. Conclusions: These findings suggest that early high quality childhood investment can result in long-term changes in social decision-making possibly attended by detectable neural markers.

2-M-43 The neural mechanisms of money illusion in the gain and the loss domains

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Money illusion refers to the way individuals' decisions are frequently affected by the nominal rather than the real value of money. In other words, the face value of money (i.e. numerical) is mistaken for its purchasing power, the true value (Cebula, 1981; Mayer & Rozier, 2000; Reinhardt, 1986; Tyran, 2007; Weber, Rangel, Wibral, & Falk, 2009). Using a factorial design combined with functional magnetic resonance imaging (fMRI), the present study examined the neural encoding of true value and face value when money illusion occurs, in both the win and loss domains. Eighteen healthy participants (8 male) participated in a gambling game. We created different face value and true value of money by manipulating magnitudes and price conditions: for the same magnitude in the cheap condition and expensive condition, the face value was identical but real purchasing power differed; for low magnitude in cheap condition and high magnitude in expensive condition, the true value was identical but the face

value differed. At the behavioral level, we found that the self-reported pleasantness of outcomes was modulated by both values. At the neural level, all winning outcome versus all losing outcome activated the anterior cingulate cortex (ACC), bilateral striatum, vmPFC and middle temporal gyrus. In the win domain, the ACC and caudate encoded the true value of money. The face value of money deactivated the caudate and vmPFC, which is inconsistent with the previous study (Weber, Rangel, Wibral, & Falk, 2009). In the loss domain, the insula encoded money illusion. The true value of money deactivated the insula and amygdala. References Cebula, R. J. (1981). "Money illusion" and migration decisions: an international comparison of the United States and Canadian experiences. Reg Stud, 15(4), 241-246. Mayer, M. L., & Rozier, R. G. (2000). Money illusion among health care providers: should we adjust for inflation in analyses of provider behavior? Soc Sci Med, 51(3), 395-405. Reinhardt, U. E. (1986). The "money illusion" in healthcare. Mod Healthc, 16(21), 138. Tyran, J. R. (2007). Economics. Money illusion and the market. Science, 317(5841), 1042-1043. Weber, B., Rangel, A., Wibral, M., & Falk, A. (2009). The medial prefrontal cortex exhibits money illusion. Proc Natl Acad Sci U S A, 106(13), 5025-5028. Yu, R., & Huang, Y. (2013). A nickel ain't worth a dime anymore: the illusion of money and the rapid encoding of its true value. PLoS One, 8(1), e55025.

2-M-44 The computational basis of moral devaluation

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Objective Recent work has shown that the subjective value of money depends on its moral consequences. Money gained immorally is subjectively less valuable, and evokes lower responses in value-sensitive brain regions, than money gained decently. Here, we used cognitive modeling to investigate (1) the computational mechanisms underlying the devaluation of money by moral transgressions and (2) if the devaluation of money can be mitigated if the money is donated to a good cause. Method Forty deciders were asked to make 164 decisions in which they chose whether to accept a higher amount of money in exchange for increased pain (in the form of electric shocks) delivered either to themselves or an anonymous receiver. The money at stake was for the decider's own profit on half the trials, and for a charity on the other half, for a 2x2 within-subjects design (pain for self/other x money for self/charity). We modeled participants' choices and response times (RT) using a hierarchical drift-diffusion model (DDM) with free parameters describing the accumulation of value driven by money and pain modulated by their recipients (self, other, charity), and used model comparison to determine how value accumulation differed as a function of these factors. We hypothesized that harming others would degrade the value of money, but that donating the money to charity would mitigate this effect, and this would be reflected in a differential accumulation of value driven by money gained from harming others versus self across conditions. Results Participants required more money to inflict pain on others than themselves, but this difference vanished when the money was donated to charity. Consistent with this, RT data revealed that participants were slower to inflict pain on others than themselves for profit, but not for charity. Model comparisons supported these findings, where the most parsimonious DDM showed the rate of money-related value accumulation was sensitive to harming others for profit, but not for charity. Specifically, money-related value accumulation was slower when profiting from harming others relative to self, and this slowing predicted higher costs on harming others than the self at the individual level (robust correlation, r = 0.80, 95% CI = [0.58, 0.92]). Conclusions An aversion to inflicting pain on others for money was reduced when the money was donated to charity, suggesting charitable donations can "launder" the devaluation of money gained immorally. Our model captures this process in the accumulation of value driven by money, where harm to others slows money-driven value accumulation, but only when the harm is difficult to justify.

2-M-45 The effect of social status on preference of distribution

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To investigate how different ways of gaining social status and the gained social status affect people's perception of deserving various outcomes, we experimentally manipulated social status that is determined by luck and efforts, which are two indicators strongly associated with the principle of fairness in the society, and examined whether the different origins of social status would modulate participants' satisfaction of monetary distribution. Specifically, in the first stage of the experiment, college students were classified as "winners" or "losers", each of which was against one opponent, based on pure luck (i.e., random drawing), or real efforts (i.e., a number-line dissection task). The winners across the two conditions of social status received the same amount of monetary reward, while the losers received no reward. In the second stage of the experiment, all participants were asked to make satisfaction ratings for the distribution of an additional amount of monetary reward between themselves and the opponent. The results showed that when participants reported that they considered the classification obtained from the first stage, in the pure luck condition, winners preferred equal over unequal distribution even when they received more additional monetary reward than the losers. Losers, in contrast, tended to prefer self-interested distribution (i.e., participants received more money than the opponent) over equal or self-less distribution (i.e., participants received less money than the opponent). Similar to losers in the pure luck condition, both winners and losers in the pure effort condition showed similar behavioral patterns of preferring self-interested more than equal or self-less distribution. On the other hand, for participants who did not consider the classification obtained from the first stage, participants preferred self-interested over equal or self-less distribution of monetary reward regardless of the origin and the actual social status they obtained from the first stage of the experiment. In summary, we found that given adequate attention placed on social status, the origin of social status as well as the gained social status modulate preference and satisfaction of monetary distribution.

N – Valuation & Value Systems

2-N-46 Opioids as force boosters: evidence from pharmacological challenge in humans

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A core problem for choosing a course of action is to maximize the expected benefits while minimizing the costs. In humans, the trade-off between costs and benefits has been typically investigated as the amount of physical effort that participants would exert for a given amount of monetary reward. One key player is this trade-off is the neuromodulator dopamine, which was found to enhance the weight of reward. Yet the neural determinants of effort cost are still poorly understood. Here, we investigated the role of the endogenous opioid system, which has been involved in both pain modulation and incentive motivation. We conducted a randomized, cross-over, double-blind, placebo-controlled experiment in a group of healthy volunteers. In active treatment sessions, participants were administered an acute dose of either morphine (a mu opioid receptor agonist) or naloxone (a mu opioid receptor antagonist). Then they performed two effort physical allocation tasks that both involved squeezing a handgrip in order to win as much as possible of a monetary incentive, which was varied across trials. In the first task, designed to measure effort intensity, participants just produced a force pulse, and payoff was proportional to the peak force. In the second task, designed to measure effort duration, participants had to maintain a target force level, and payoff was proportional to time spent above the target level. We observed that both effort intensity and duration were modulated by opioid treatments (enhanced by morphine and decreased by naloxone), relative to placebo sessions, without any interaction with

incentive level. These results suggest that opioids might shift the cost/benefit trade-off so as to enhance effort production, possibly by alleviating aversive signals meant to prevent limit effort expenditure. This would confer to the opioid system a boosting role that may complement dopaminergic functions: opioids would alleviate effort cost while dopamine would emphasize expected benefits. We are currently examining this hypothesis using computational modeling of effort allocation.

2-N-47 Visual features and value based decisions

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Research has shown that visual saliency influences visual attention and biases choice behavior. Several studies explored how manipulating extrinsic stimulus features (e.g., brightness) influence the decision alongside the intrinsic value of the stimulus (i.e. its subjective value). However, it is still unclear what role different objective visual features play in the construction of the intrinsic value of a given stimulus and how this effect propagates to influence the valuation processes. Research in visual aesthetics addressed the former point explicitly by showing that individual differences in response to color and spatial structure shape aesthetics preferences, that is, the subjective value of a given stimulus. Here, we studied the role of visual features in value-based preference formation and how they affect binary choices using items from three distinct categories: fractal images, faces and snack foods. We focused on four visual features: Hue, Saturation & Color-Value (CV) of the HSV color space, and Spatial Frequency (SF). We examined the relations between these features, preference formation and choices on a large dataset of 1738 participants, obtained from 9 independent laboratory and 6 online samples (of which, 3 samples are preregistered direct replications). In some studies participants ranked items on a liking scale or performed an auction for snacks. In other studies, they made binary choices and then ranked items on a liking scale. We studied three main questions: 1) Is there a correlation between visual features and preference rankings? 2) Do visual features explain choices above and beyond preference rankings? 3) Do individual differences in ranking variability correlate with choice consistency? We found a unique pattern for the three categories, showing that visual features contribute to preference formation, apparent in both rankings and choices. Specifically, Hue influenced preference formation across categories while CV & SF also influenced fractals rankings, saturation influenced faces rankings, and SF influenced snacks rankings. In binary choices, we found that over and above value contribution, participants tended to choose items with higher Hue in fractals, higher Hue & saturation in faces, and lower CV in snacks. Finally, we found there are category specific individual differences in shaping the relation between visual properties and value formation. The current study provides evidence for a stable role of visual features in value-based decisions, and provides support for the influence of visual features in the valuation processes through their effect on preference formation.

2-N-48 Integrating value across features of multi-attribute options does not require intact ventromedial prefrontal cortex

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BACKGROUND: Real-life decisions are generally made between options with multiple value-relevant attributes. Consumer research suggests that the value associated with each attribute is integrated in a global value, to allow comparisons with other options. The ventromedial prefrontal cortex (vmPFC) has been proposed as the neural substrate of this integration process. BOLD signal in this area correlates with subjective value, including of explicitly multi-attribute decision options. This region is functionally connected with areas processing different value-relevant attributes, consistent with the notion that it may integrate several sources of information to produce an overall value estimate. A recent study from

our lab found that damage to the ventromedial frontal lobe affects which value-predictive attributes are used to make decisions between complex options (politicians). OBJECTIVES: We followed this up here with a simpler task, asking whether intact vmPFC is necessary for integrating the value of two attributes to make a choice. METHODS: A novel task using object-like artificial stimuli (fribbles) was designed to provide experimental control over the attribute-value information available to the participants. Ten patients with vmPFC damage, 10 patients with frontal damage sparing vmPFC, and 21 healthy controls learned the monetary value of 6 features along two attributes of the fribble stimuli, and then chose between pairs of fribbles. In one condition, only one attribute distinguished the value of the two options (Single-attribute). In the other, the previously-learned values of two attributes would lead to the optimal choice (Integration). RESULTS: Generalized estimating equations confirmed that all groups integrated value across attributes, as the combined value of the two learned attributes better predicted choice than the value of each attribute individually. No group by value interaction was found; i.e. vmFPC patients did not perform differently from controls. Across groups, reaction times were significantly longer and errors more frequent for Integration trials compared to Single-attribute trials, but there were no significant differences between groups. CONCLUSIONS: The data suggest that vmPFC is not critical for integrating the value of two attributes to inform multi-attribute choice, at least when the values of attribute features are explicitly trained. These results do not support a simple model of vmFPC as a subjective value integrator. Instead, we argue for a more nuanced view, distinguishing different kinds of value-relevant information, and addressing how value information interacts with attention during stimulus processing.

2-N-49 Understanding the motivational side of placebo effects: Placebos are mediated by neural activity in the brain?s valuation and motivation system and enhance ?wanting?.

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Background: Evidence from cognitive neuroscience suggests that placebo responses recruit neural pathways linked to reward and motivation. If so, positive expectancies induced by suggestions provided by a placebo cue (i.e. informational cues, labels, price) should be (1) be mediated by brain regions sensitive to reward and (2) enhanced when participants are in a state of high motivation. Methods: We conducted two independent studies using functional magnetic resonance imaging (fMRI, study 1, N=30) and behavioral testing (study 2, N=88). In the first study, we used a previously developed fMRI task to investigate price cue effects and applied whole brain mediation analysis to investigate brain mediators price placebo effects on how much participants enjoyed consuming different wines. Second, we crossed expected and actual consumption of an energy drink (EnD) and measured wanting - the allocation of cognitive effort according to the magnitude of by trial-by-trial incentives. We further modeled wanting within a cost/benefit framework to assess how the expected EnD consumption (EnD label) changed the value of effort. Results: Study 1: fMRI revealed that the brain's valuation and motivation system (i.e., the vmPFC and vStr) formally mediated the effect of price cue on taste enjoyment ratings (SVC pFWE<0.05), and was moderated by task-independent responses to monetary rewards in the ventral striatum. Study 2: Model-free analyses showed that expected, but not actual EnD consumption, translated into enhanced 'wanting', which implied a facilitation of cognitive effort by the placebo cue in high incentive trials only (ß = 0.05, SE = 0.02, p = .002, 95% CI [0.02 - 0.09]). Model-based analyses revealed that the EnD label enhanced participant's reward sensitivity ($F(1,87)=9.56$, $p<0.01$) without changing their sensitivity to the cost ($F(1,87)=1.53$, $p=.21$) of cognitive effort. Conclusion: These findings provide convergent, direct neural and behavioral evidence for enhanced motivational processes underlying placebo responses of price tags and brand labels. Our findings also parallel findings from placebo

analgesia, and thus suggest that enhanced motivational processes in brain and behavior might constitute an elementary neurocognitive mechanism for placebo effects across domains.

2-N-50 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 will not change choice behavior. However, recent evidence suggests purely nominal changes in prices can influence consumer behavior. Our understanding of the mechanisms that mediate this effect is limited. While there is evidence that activity in the MPFC is positively correlated with the magnitude of monetary rewards and negatively correlated with stated prices (Knutson, 2001, 2007, Weber et al., 2009), it is unclear whether price information is encoded as a reduction in the value of particular goods or money more broadly. We sought to examine whether the encoding of price information within the vmPFC differs from rewards including money. Methods: Nineteen subjects participated in an fMRI experiment. The experiment consisted of two scanning conditions followed by a behavioural condition which elicited incentive compatible valuations. In the Income condition, three goods were presented to a subject at one of two value-levels for each item (1 or 2 chocolate bars, 16 or 32 GB USB-key, and $6 or $12). Each subject was asked to consider how much the bundle was worth to them. In the Price condition, the objects were identical to those in the Income condition, with one critical difference - the money amount now determined the price to pay (out of $30) for the other two goods (the USB-key and chocolate). Importantly, the net value of the trials under the Price condition and under the Income condition were identical, since the price was either $24 (leaving the subject with net $6) or $18 (net $12). In order to examine the differences in neural activity between the two conditions, we applied Multivoxel Pattern Analysis (MVPA) to the vmPFC. Results: Voxels in the ventral vmPFC significantly distinguish Income trials from Price trials. For each good separately, voxels significantly classify high- from low-value trials, holding the two other goods constant. When price was varied, there is a considerable overlap with the value of the two other goods, but importantly, not with money directly. Finally, the value representation of money is different when comparing the Income and the Price conditions. Conclusions: Our results begin to suggest that the neural representation of prices within a subregion of the vmPFC is consistent with a modulation in goods-value, and that a distinct subregion represents monetary value. These results may suggest a neural instantiation of the discrepancy between economic theory and observed behavioral effects of real vs. nominal price changes.

2-N-51 Salience-driven value construction for choice under risk

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Over the past four decades, prospect theory has been the standard model to capture choice under risk. Most experiments testing prospect theory, however, have focused on options with only two possible outcomes whereas real-life options generally involve multiple possible outcomes. Therefore, it is unclear whether prospect theory can be applied to more complex risky options and what are the mechanisms involved in the construction of reward value for such options. To answer these questions, we utilized a combination of experimental and modeling approaches to examine choice between gambles with multiple outcomes. Although our results supported several assumptions of prospect theory for simple gambles, they show clear deviations from this theory for complex gambles and moreover, revealed how reward salience can influence the construction of value. First, we found that when evaluating simple gambles human subjects constructed reward values using a concave utility function and an inverted S-

shape probability weighting function as predicted by prospect theory. However, subjects did not exhibit distorted probability weighting when evaluating individual outcomes of complex gambles (gambles with three possible outcomes). Second, to construct the overall value, most subjects assigned a larger weight to the outcome with the largest reward magnitude compared to the other two outcomes. This result illustrates how the salience of possible outcomes in terms of reward magnitude can influence the construction of reward value. Finally, we found that the differential weighting of possible outcomes by reward magnitude enabled subjects to more easily and quickly choose between gambles with similar subjective values. Overall, our study reveals that evaluation of complex gambles involves selective processing of reward information as well as dissociation between information used for valuation (expected utility) and information used for the weighting of possible outcomes (magnitude).

2-N-52 Adapting choice behavior and neural value coding in monkey orbitofrontal cortex

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Behaving organisms face constantly changing environments, requiring nervous systems to encode broad ranges of information efficiently within finite coding constraints. In sensory systems, this problem is widely believed to be addressed by adaptive coding mechanisms like temporal adaptation and spatial normalization. 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 is largely unknown. Here, we present data from a saccadic choice task in which trained monkeys chose between two options differing in reward magnitude and juice type. Blocks of trials were composed of a mixture of "adaptor trials" and "measurement trials". In measurement trials (identical across blocks), monkeys chose between an unvarying reference reward and one of five variable rewards. These trials quantify the monkey's probability of choosing the reference reward as a function of the magnitude of the variable reward; a choice curve. Across blocks, we systematically varied the structure of the adaptor trials to induce narrow or wide background reward environments. While monkeys performed this task, we recorded single-unit activity from orbitofrontal cortex (OFC; area 13). We found that adaptor variability had a significant effect on both choice behavior and neural value coding in OFC. Consistent with an adapting decision mechanism, monkeys exhibited steeper measurement trial choice curves in narrow vs. wide background reward environments. Out of 352 OFC neurons, 103 exhibited a significant ($p<0.05$) modulation by value in the measurement trials (cue or reward period). Consistent with neural adaptation, the strength of value coding was stronger in narrow vs. wide blocks. We then tested if the extent of this coding difference (narrow vs wide) corresponded to the behavioral difference in the choice curve slopes (narrow vs wide) across sessions. In the cue interval, cells that exhibited a significant modulation by value exhibited a strong correlation between neural and behavioral adaptation (cue interval: rho=0.57, p=0.009) while there was no correspondence in the reward period. These results indicate a neurometric-psychometric link between choice performance and value coding in OFC neurons, suggesting a neural mechanism for adaptive decision-making. Ongoing work will examine whether adapting choice behavior and OFC responses correspond to predictions of divisive normalization-based models of history-dependent decision making.

Sunday October 8, 2017

B – Choice & Choice Mechanisms

3-B-1 Investigating the origin and consequences of endogenous default-options in repeated economic choices tasks.

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Introduction: Dominant value-based decision-theories states that economic choices are made by independently computing the value of available options and choosing the option with the highest value. Recent evidence, however, suggest that individuals have endogenous preferences toward categories of ecological options (e.g. food items), which frame the choice computations, shape the neural comparison process, and create default policies. Yet, little is known about how such default-policies might impact decision-making in classical economic choices (e.g. between lotteries). Here, we suggest that two factors might contribute to create and modulate endogenous default-option policies with abstract options such as lotteries: time pressure and time spent in the task. Those factors could account for a natural tendency to prefer certain types of options (e.g. risky or safe lotteries), and a tendency to implicitly learn a default-option from preferences revealed in past choices. Methods: We designed two binary-choice tasks, where participants had to choose, at each trial, between two risky lotteries. Critically, we orthogonalized three main factors: the time spent on task, a time pressure instruction, and the values of lotteries. This last factors was used, in a between-subject design, to manipulate which option (safer vs risker lotteries) would be predominantly chosen by participants. Choices and reaction times where then analyzed using combinations of linear mixed-effect modelling, and computational modelling inspired from Prospect Theory. Results: Our modelling results show that decision-makers' choices between risky lotteries combine expected utility computations with a default-option weight toward a category of lottery (safer versus riskier). Our results further show that two key experimental features -the time spent on task and the level of time-pressure- have significant and dissociable impacts on those default-option weights, enhancing choices biases by experience-dependent versus a priori defaults-options. Discussion Overall, these investigations reveal that individuals' choices may be biased so as to save time and computational resources, while remaining compatible with their preferences. They also suggest that some neglected experimental features (time pressure, task duration) have a significant impact on the modelling of economic preferences.

3-B-2 The dynamics of selective integration in the brain

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Introduction. Due to the nature of economic choices, higher-level and inherently subjective, studying the underlying mechanisms in a controlled fashion has proven hard. Recently efforts have been made to study economic decision-making under the sequential sampling framework developed to understand perceptual decisions. This approach offers better control over the visual and temporal properties of the information, allowing clearer insights into how higher-level decisions are computed in the brain. Under this framework it has been revealed that a selective integration policy can account for these biases. The model proposes a local competition among features. Biases then originate from the down-weighting of the local ?losers?, i.e. those feature values that carry less evidence in favour of the correct response relative to their local counterpart (?winners?). Objective. Though the model has been validated for behaviour, little is known about the underlying neural dynamics. Using the high temporal resolution of EEG, we set out to overcome this limitation. We hypothesised that if selective integration is a possible neural mechanism, we should find differential processing of samples based on its relative value, specifically a reduced processing of losing samples compared to winners. Methods. During the experiment, participants were shown pairs of vertical bars that varied in length over time at a rate of 2Hz. After observing 9 successive pairs, they were asked to choose which stream (left or right) contained the highest/lowest bars on average. The frame of choice was manipulated in 2 separate recoding sessions, in order to disentangle sensory from decisional information. Results. Behavioural results were

in line with previous research: losing samples had less influence on choice than winning samples. Model fitting also showed underweighting of the losing samples. On the neural level, we used a regression-based approach to study single-trial variability in the brain signal related to the encoding of winning versus losing samples. We collapsed data from the two recording sessions, creating a common decision variable (DV) that was orthogonal to the perceptual value. When bars were divided based on their relative value (winner vs. loser), we observed a significant contralateral occipitoparietal modulation around 250 ms after sample onset. For the same electrodes, this categorical difference was further modulated parametrically by the DV of the sample; again showing reduced encoding of the losing sample. Conclusion. We show for the first time that selective integration is not only a suitable model to predict choice behaviour, but also has a neural foundation. Selective modulation of feature values can occur as early as 250 ms in early-stage decision signals.

3-B-3 Causal contribution of the frontal eye fields to perceptual decision formation

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The frontal eye fields (FEF) have traditionally been thought to underlie visual attention and the preparation and execution of the saccadic eye movements, but their role for perceptual decision formation remains unclear. For instance, a substantial debate in the monkey and rodent literature centers on the question whether the FEFs supports either gradual integration of perceptual evidence during decision formation or whether it supports categorization of choice alternatives at the end of the choice process (e.g. Hanks et al 2015, Nature). Therefore, it is currently unclear whether neural activity in the FEFs is causally necessary for integrating evidence towards a decision or whether this structure simply implements the final product of this process. In the current study, we combined behavioral psychophysics with transcranial magnetic brain stimulation (TMS) to temporarily manipulate FEF activity during the decision formation process in humans. Participants (N=23) performed two-alternative forced choices (2AFC) which of two simultaneously presented trains of randomly timed tactile stimulation contained more stimuli. On each trial, two TMS pulses (10 Hz frequency, intensity 110% resting motor threshold) were applied over the left FEF at one of two possible timepoints during decision formation - either in the middle of the process where it should interrupt evidence accumulation, or at the end of the process, where it should interrupt categorization of choice alternatives. Participants also completed the same protocol with stimulation over the vertex, to control for TMS side effects. We found site- and timing-specific stimulation effects on discrimination performance: Earlier but not later stimulation decreased choice accuracy, indicating a causal involvement of FEF specifically during integration of perceptual information for choice. Our results demonstrate that the human FEFs support evidence integration and not choice alternative categorization during perceptual decision-making, thus suggesting differences in the neural implementation of choice processes in the human versus rodent brain.

3-B-4 The deficiency of Akt1, a candidate gene for schizophrenia, affects reward prediction error and brain electrophysiological activity during probabilistic decision making in mice

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Making appropriate decisions involves the ability to update information of alternatives from previous experiences. In particular, the updated reward prediction error (RPE) - a discrepancy between the predicted and the actual rewards - is regarded as being encoded by dopamine neurons. Recent studies suggest that dysfunction of RPE might link abnormal dopamine systems and therefore the formation of psychotic symptoms in schizophrenia. Accumulating evidence from human genetic studies and animal studies further suggests that AKT1, a schizophrenia candidate gene, is involved in the pathogenesis of

schizophrenia and dopamine-dependent behaviors. Recent findings also suggest that AKT1 plays an important role in the regulation of schizophrenia-related behaviors, methamphetamine-induced behavioral sensitization, goal-directed behavior, reward prediction error in decision-making, and striatal neuronal activity, particularly in Akt1-deficient mice. Accordingly, the measurement of RPE and event-related electrophysiological responses in animal models might reveal the involvement of Akt1 in decision making and the pathogenesis of schizophrenia. Male Akt1+/- mice and their wild-type littermate controls were used to perform a 2-choice probabilistic decision making task with different reward rates. Our behavioral data indicated that Akt1+/- mice took fewer trials to consistently choose the high reward option compared to controls. Trial-by-trial choice behaviors of mice were further analyzed to estimate parameters for value-updating rule and choice rule using Bayesian hierarchical model and reinforcement learning. Our model-fitting data revealed that Akt1+/- mice had a higher learning rate but a lower choice consistency compared to controls. Based on these findings, in vivo local field potential recordings were conducted in the dorsomedial striatum of mice during different stages of the decision-making process in the task. Our electrophysiological results revealed a genotypic difference in the power spectrum density of local field potentials at the baseline. The event-related potential data further indicated genotypic differences at different stages of the decision-making process in different sections of reward rate. Collectively, these results support that the deficiency of Akt1 can result in the alteration of behavioral response, RPE signaling, and brain activity in probabilistic decision making. Findings from this study shed light on our understanding of the role of Akt1 in reward-based decision-making and the involvement of this gene in the pathogenesis of schizophrenia.

3-B-5 Gaze patterns reflect loss aversion

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Loss aversion, the tendency to avoid losses over acquiring equivalent gains, is one of the most commonly observed biases. It has been robustly demonstrated that participants typically accept a 50-50 chance to win or lose a certain amount of money, only when the gain is nearly twice as much as the loss. Typically loss aversion has been modeled based on behavioral outcomes. These models implicitly assume that the decision is instantaneous. However, common experience suggests that the decision-making process is far more elaborate: one may visually scan the gambles presented -- multiple times on occasions -- before accepting or rejecting the offer. We chose to understand how, if at all, gaze patterns during decision making both reflect and influence loss aversion. To this end, we adapted the attentional drift-diffusion model (aDDM) that incorporates gaze data into an accumulation-to-bound decision-making process. 32 participants, recruited via the Wharton Behavior Lab, enrolled in the study. Participants received an endowment of $10 in cash that could be used to pay for the incurred losses. The experiment consisted of two blocks of 100 trials each. In each trial the participant accepted or rejected a series of mixed gambles with equal probability of winning or losing. Trials were sampled from a matrix with potential gains and losses ranging from ±$1 to ±$10 in increments of $1. An SMI-red eye tracker was utilized to track the eye movements and pupil diameter at the rate of 120 samples/sec. Several models were tested to understand the process underlying decision making in these circumstances: Model 1 was a standard DDM, which is agnostic to visual scanning behavior. Models 2-5 were versions of the aDDM; these models differed in how the gain and loss items affected the drift rate. The items had a similar effect on the drift rate in models 2 and 3, and a differential effect in models 4 and 5. Most of our participants robustly displayed loss aversion (mean=2.25, median=1.85, 27/32 > 1). Participants scanned the offers several times (2.72±1.6) before making a decision. The probability of accepting a gamble increased when the participant fixated longer on the gain option. The simple diffusion model (model 1) was

outperformed by the aDDM for all 32 participants. Following a rigorous AIC- and BIC-based model comparison, models 4 and 5 best fit the data in 30/32 participants. These results indicate that gaze patterns reflect decision making over gambles with gains and losses. aDDM models that incorporated a differential influence of loss and gain performed better than other models. In other words, looking at the loss option influenced the decision process more than the gain option. Thus, information acquisition and loss aversion are intimately related processes.

3-B-6 The neuro-computational basis of conflict resolution between model-free and model-based valuation systems

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A growing body of work suggests that the brain assigns value to options at the time of choice using, at least, two distinct classes of valuation systems: model-free systems, which assign value based on the history of previous reward experiences with similar options, and model-based systems, which compute values at the time of decision using information about the option and environment at the time of decision. Although these two valuation systems often assign similar relative desirability to the different options, they do not always do so. When conflict arises, with the model-free system favoring one option, and the model-based system favoring another, the brain needs to resolve the conflict to select one of the options. We study the neuro-computational basis of how these types of conflicts are resolved using a new behavioral paradigm designed for this purpose. Human subjects are required to make binary choices between a left and a right option. Each option consists of a bundle of two items: a lottery and a fractal. The reward and probability associated with the lotteries are shown on the screen and vary throughout the trials. Each fractal is associated with a fixed reward of known value, but the probabilities of obtaining a reward from each fractal are unknown and drift slowly, and therefore must be learned based on the outcome of previous trials. Before making each choice, the subject is told the probability that the reward for the selected options will be drawn from the fractal or the lottery component. We used the psychometric data to compare several computational models of competition between the model-free and model-based valuation systems, and fMRI data to characterize the neural basis of the associated computations.

3-B-7 Accounting for individual differences in gaze-weighted evidence accumulation improves prediction of individual consumer choice

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Study objective: Why do consumers differ in their ability to consistently choose items that they like most from small choice sets (e.g. choosing between a Twix, Snickers and Mars)? Prior studies showed that choices are driven by accumulation-to-bound decision processes, where the accumulation process is guided by visual fixations (with lower accumulation rates for items that are currently not fixated). Crucially, those studies relied on group results that are not sufficient for the level of understanding of individual consumers that is needed in everyday marketing practice (e.g. personalized advertisements). We hypothesize that the variability which we observe in consumers' choice behavior originates from variability in the strength of the fixation-bias effect. Methods: To test this, we reanalysed previously published data (Krajbich et al., 2011) from a prototypical value-based choice task and focused on differences between participants (here, participants made choices between three snack food items, while their eye movements were being recorded). To investigate the computational algorithm underlying individual choice behavior, we developed a new computational model, called Gaze-weighted Linear

Accumulator Model (GLAM). GLAM assumes evidence accumulation towards a decision threshold and an accumulation bias for un-fixated items, akin to existing models. GLAM can be fitted in a hierarchical Bayesian framework, allowing efficient estimation of individual participant parameters, even with relatively small amounts of data. On an individual level, we assessed both, the relative fit of the model (compared to a variant without a fixation bias mechanism) and the absolute fit, using out-of-sample predictions. Results: We found that individuals differed substantially with respect to their reaction time and probability of choosing the highest rated item. Individuals also showed an overall positive relationship between gaze and choice (longer gaze corresponds to higher choice probability), but the strength of this relationship was highly variable across individuals. GLAM accurately predicts these differences and outperforms a model which does not assume any influence of gaze on choice for 26 of 30 (87%) participants. Conclusions: Taken together, our findings suggest that there is a strong relationship between individuals' gaze and choice behavior and that this relationship is highly variable across individuals. Using a newly developed computational model, we found that this variability results from variability in the strength with which individuals discount the evidence of unattended items during decision formation.

3-B-8 The influence of visual attention on memory-based decisions

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A recent study indicates that episodic memory biases value-based decisions (Gluth et al., 2015). According to this memory bias in binary choices participants tend to choose the remembered option when they forgot the second option, unless the remembered option has an extremely low value. We address a possible explanation of this influence of memory on value-based decisions: visual attention. Notably, it has been shown that visual attention can also bias decisions, as people tend to select options they have looked at longer (Krajbich et al., 2010). We expect to replicate the memory bias on preferential choices reported in Gluth et al. (2015). Moreover, we predict that attention is mediating the memory bias because i.) people fixate more on remembered options and ii.) options that are fixated more (or longer) are more likely to be chosen. In two eye-tracking (within-subject) experiments, participants perform a task consisting of four phases: encoding, distraction, decision and recall phase. During encoding participants learn the association between six snacks and their locations; afterwards they perform a numerical two-back working memory task. During the decision phase they decide between two food snacks they either see directly (one third of trials) or retrieve from memory (two third of trials). In the first experiment participants see the options simultaneously while in the second experiment the options are shown sequentially. Lastly, in the cued recall phase participants recall the snacks. To predict choices and response times as well as to describe the interplay of attention, memory and decision-making in a cognitive modeling framework, we will revert to a well-established account: the Drift Diffusion Model (DDM; Ratcliff, 1978; Ratcliff & Rouder, 1998). The DDM assumes a sequential sampling process of decision-making: people consider advantages and disadvantages of the available choice options, accumulating noisy evidence. The choice is made as soon as the evidence-accumulating decision variable crosses a decision threshold. We will combine the attentional DDM (Krajbich et al., 2010) with a memory-based sequential sampling model (Gluth et al., 2015). We will present behavioral, eye-tracking and computational results and discuss the findings in light of their meaning for everyday decisions. Establishing the memory and the attentional bias in (memory-based) preferential choices as well as integrating them into a common framework is an important step towards a mechanistic account of complex, every-day decision-making behavior. Awareness of these biases can improve implementation of policies that aim to support people to make more adaptive decisions.

C – Computational Modeling

3-C-9 Exploring Context Dependency Using a Dynamical Model

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Objective: The fundamental assumption in most of traditional rational theories of choice, implies that the decisions are made independent to the context effects. This assumption means each option should be evaluated independent to the other available options in an absolute manner. This property, which is called Independence of Irrelevant Alternatives (IIA), entails that a chooser who decides among a number of options, should not be influenced by the quality and number of available options. However, research has consistently shown that the choice set by itself can affect the valuation and consequently decisions in different ways. Here we study context dependency of choice behavior and provide a mathematical model to explain three important context effects (similarity effect, attraction effect, and compromise effect) based on neuroscientific and behavioral evidences. Methods: The proposed dynamical model relies on three fundamental assumptions; 1. The value of each option should be normalized by the summation of the values of all available options in the choice set. 2. The value of each option can reduce or increase the value of other options, based on the similarity between each pair of options (Mutual Inhibition/Excitation, MIE). 3. A normal distribution is considered around each value to account for the stochastic features of decision processes. To simulate the decision processes in the presence of context effects, in this model, an attractor on a plane (attractors' plane) presents each option. The process starts from the center of attractors' plane and finishes when a threshold is passed or the decision time is expired. The orientation and the distance of each option from the center is calculated according to the final value of each option after MIE (decision potential) and its similarity with other options. Results and Conclusion: To evaluate the performance of the model, five different scenarios are simulated. In the first scenario, a decision should be made between two options with high decision potentials (known as target and competitor). In the remaining scenarios, the decision should be made among three options; target, competitor, and a third option as the decoy. The quality of the decoy option changes in four ways based on its similarity to the target and competitor, and also its dominancy in the choice set. The proposed dynamical model not only captures all the context effects in these five scenarios, but also it pushes our understanding of context dependent effects by predicting the direction and the strength of these effects. Additionally, this model is compatible with the existing behavioral data on context dependency of human decision-making processes and provides information regarding their triggering mechanisms.

3-C-10 The multiplicative role of attention on choice

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Objective: Decision making is often understood as a process of noisy evidence accumulation, by which a decision is made when the relative evidence for one option surpasses a predefined boundary. Prior work has identified a significant role of attention in the choice process. This attention-choice link brings up a key question, which is whether attention merely adds evidence, or if it enhances (multiplies) the incoming evidence for the looked-at option. The answer to this question is critical to understanding how attention influences the choice process. The attention-driven choice process has been described by a variety of sequential sampling models. For example, the aDDM (attentional drift diffusion model, Krajbich et al. 2010) is one such model that can account for choices, RTs, and eye movements. Crucially, the aDDM posits that looking at one option introduces a bias toward that option; this is represented by a (multiplicative) discount on the evidence accumulation rate for the unlooked-at option. An alternative (additive) version of the attention-choice link has also been postulated whereby the choice bias results

from a fixed increase in evidence for the looked-at option, so the attention-choice link does not vary with the value of the options. The crucial difference between these models rests in the value-attention interaction; while an additive model implies that the degree of attentional influence is independent of the values of the options, the (multiplicative) formulation of the aDDM requires an interaction between the two, leading to stronger relationships between attention and choice for high value options. Methods: Here, we examine data from six separate binary-choice studies in order to characterize the relationship between value and choice that best fits the data. We use a combination of statistical methods, including generalized linear mixed models, simulations, and model fitting, to examine the choice, RT, and attentional predictions of each model and compare them to the observed data. Results: Although both models provide adequate fits to the data (as measured by traditional DDM fitting procedures), we ultimately find that in six different datasets, the attention-choice relationship in the data is inconsistent with the additive model. That is, in examining more nuanced predictions from each model, the effect of attention on the choice process is indeed modulated by the values of the options, as suggested in the aDDM. Conclusions: These results shed important light onto the exact nature of the relationship between attention and choice. Specifically, we conclude that visual attention interacts with the values of the choice options (as predicted by the aDDM) to produce robust, reliable attentional effects on the decision process.

D – Consumer Behavior & Marketing

3-D-11 Delineating feeling and thinking during advertisement viewing: Neural reliability in temporal cortex and fusiform gyrus predict population ratings of TV commercials

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Both brain activation and intersubject reliability of brain responses - temporal correlation of neural patterns across individuals - at temporal cortex are suggested tobe a sign of arousal caused by and engagement with the presented stimuli, be they narrated or retold stories (Wallentin et al., 2011; Silbert et al., 2014), political speeches (Schmälzle et al, 2015), video clips (Nummenmaa et al., 2014), movies (Hasson, Malach & Heeger, 2010) or commercials and TV shows (Dmochowski et al, 2014). It is unclear, however, whether (a) neural activation and reliability explain unique variances in engagement; and (b) whether neural reliability is associated with different aspects of engagement, namely information processing and emotional processing. We are particularly interested in the neural processing of TV commercials, whose dual goals of transmitting information and evoking emotions involve likely different brain processes. In our first study, participants (N = 40) watched 35 commercials (25-60s) during fMRI scanning. The commercials' experiential (i.e. whether they are emotionally engaging) and informational (i.e. extend to which they provide information on product benefits) qualities were rated by a separate group of participants (N = 117). While neural activation and reliability at the temporal cortex correlated with the experiential quality of the commercials, intersubject neural divergence at the fusiform gyrus correlated with the informational quality. In addition, neural activation and reliability at the temporal cortex each uniquely explained variance in experiential quality. Moreover, population-wide ratings of ad recognition corresponded with neural reliability at temporal cortex, while ratings of message clarity corresponded with neural divergence at fusiform gyrus. We found similar results in a replication study where participants (N = 20) watched the same set of commercials but with different MRI acquisition parameters. In addition, we extended the findings with a third study, in which 28 participants watched 18 movie trailers (66-150s). Here, we found that neural reliability (not divergence) at both temporal cortex and fusiform gyrus was correlated with star ratings by an external group (N = 96). In sum, using a large sample of participants (total fMRI sample N = 88), we showed that, consistent with previous

findings, both neural activation and reliability at temporal cortex predict the experiential quality of dynamic stimuli, especially when they have a strong narrative component. On the other hand, informational quality may be reflected by the heterogeneity in neural responses at the fusiform gyrus, which is associated with semantic processing. Further research is needed in order to ascertain the role of neural divergence.

3-D-12 The association between insurances and personality traits

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Objective: Even though an increasing number of researchers are combining assessments from psychology and economics, none have studied the association between personality traits and purchasing certain insurance types, as well as between personality traits and possessing a higher or lower number of insurances. We study these associations while accounting for previously related household characteristics and variables related to risk. Methods: In a non-convenience sample of 198 working-age males (38.95 ±6.7 years), we asked participants to fill out the Neuroticism-Extraversion-Openness to experience Five Factor Inventory (NEO-FFI) and the Reuter and Montag?s revised Reinforcement Sensitivity Theory Questionnaire (rRST-Q, assessing BIS/BAS/FFFS). Additionally, we asked participants to indicate whether they had purchased any of five different insurance types and to answer questions concerning their current household and financial situation, as well as further questions assessing impulsivity, risk optimism, and risk tolerance. After performing sanity checks in the form of pairwise correlations, we conducted logistic regression analyses for each insurance type, as well as multiple regression analysis for the number of insurances. Results: We find that conscientiousness is positively associated with having private accident insurance, pension insurance, and private liability insurance. Additionally, we find that individuals with private accident insurance score lower on the Behavioral Activation System (BAS) scale and those with pension insurance are less open to new experiences. While legal and life insurance are found to not be associated with personality traits, we find that having a higher number of insurances is associated with being more conscientious, agreeable, and neurotic. Conclusions: Despite being the first exploratory study linking insurances with personality traits, our results could have important implications for insurance companies and consumer protection agencies. On the one hand, insurance companies could use the findings to improve ?Ad-targeting? to sell more suitable insurance products. On the other hand, personality assessments could be included as part of financial advice to protect highly conscientious individuals from making irrational financial decisions (e.g. purchasing private accident insurance, despite having a very low income and being very risk averse). Acknowledgements: This study was partly funded by the Frankfurt Institute of Risk Management and Regulation.

E – Emotion & Affect

3-E-13 Integrating Incidental Affect into Consumers Experiences: Dissociable Roles of Valence and Arousal in Affect Infusion Processes

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Extent research in social psychology has shown that incidental affect could infuse people?s predicted utility (i.e., preferences at time of choice). However, it is unclear whether and how incidental affect might infuse the computation of people?s experienced utility (i.e. valuation at time of consumption). In two multi-method studies combining fMRI, skin conductance recording (SCR), facial affective recording (FAR) and behavioral ratings, we studied whether and how people?s experienced utility across sensory modalities (i.e. taste and aesthetics evaluations) were altered by incidental rewards. By decomposing

incidental affect into valence and arousal, we examined how these two affect components contribute to affect infusion processes. Subjects were informed that the goal of the study was to examine their neurophysiological responses to primary rewards (wines and images with different valence) and secondary reward (money). Unbeknownst to them, we delivered incidental rewards from a lottery to manipulate their levels of incidental affect. In S1, subjects evaluated liking of wines after trial-based incidental reward manipulation ($0, $50 or $200) while their brains were scanned by fMRI. In S2, subjects provided their aesthetic evaluations of images after each incidental reward manipulation (?0 or ?15) while their arousal and valence were sampled by SCR and FAR. Behaviorally, mixed regression found main effects of incidental rewards on evaluations of wines and images. fMRI analysis revealed that such modulation of experienced utility was positively associated with brain?s valuation system (e.g. striatum and vmPFC) and arousal system (e.g. amygdala and insula). Multi-level moderated mediation models uncovered how neurophysiological signals corresponding to valence of affect (BOLD in brain?s valuation system in S1; FAR in S2) and arousal of affect (BOLD in brain?s arousal system in S1; SCR in S2) contributed to affect infusion processes. We identified a unique interaction of valence and arousal: the valence of affect mediates affect infusion, and the extent of such mediation is moderated by the arousal of affect. Our studies provide behavioral evidence across sensory domains that incidental affect increased individuals? experienced utility. By using fMRI, we identify key brain regions that are involved in experienced utility and arousal coding that underlie these effects. We decompose affect into valence and arousal by measuring these concepts directly with psychophysiological measures. By doing so, we provide novel evidence that the valence of affect and arousal of affect play dissociable mediation and moderation role in affect infusion processes.

3-E-14 Stress exposure and cue-induced craving exert distinct time-dependent influences on subjective valuation

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OBJECTIVE: States of stress and craving are both thought to play a critical role in driving reward pursuit in ways that are important in addiction. However, it is unclear whether these constructs influence reward valuation in similar ways (e.g., by both increasing the subjective value of rewards), or a distinct manner (e.g., by stress rendering individuals more susceptible to cues that induce craving without directly affecting reward valuation). The primary goal of this study was to identify the specificity and independence of stress and craving effects on reward valuation, and to characterize how they unfold over time. METHOD: Healthy non-dieters were randomly assigned to a Control (n=30), Stress (n=30), or Stress&Craving (n=37) group. All participants completed an economic decision-making task in which they reported their willingness to pay ($0-10) for the opportunity to purchase food items. These 'bids' were placed continuously for different quantities of each snack, allowing us to capture dynamic changes in participants' subjective value of food rewards over time. Bids were realized using a standard economic (Becker-Degroot-Marschak) auction procedure at a fixed low hazard rate. After baseline bids were acquired, participants either underwent a physiological stressor (Stress and Stress&Craving group) or a control task (Control group), before completing the bidding task. After the stress task, the Stress&Craving group additionally completed a cue-induced craving manipulation with one of the foods. Saliva samples were collected throughout to assess neuroendocrine markers of stress response. RESULT: Perceived stress and salivary cortisol levels were greater in both stress groups compared to controls, confirming the efficacy of our stress manipulation. Bids did not differ between groups at baseline, however, after their respective manipulations, the stress groups demonstrated a marked increase in bids relative to controls. Interestingly, these effects unfolded differently over time: whereas the Stress&Craving group showed an

immediate increase in bids that steadily diminished over time, bids in the Stress group increased progressively over time, peaking only toward the end of the task. In contrast, bids in the Control group consistently decreased over time. Further, individual differences in perceived craving success and stress level supported these time scale dynamics. CONCLUSION: Our results suggest that both acute stress exposure and cue-induced craving enhance the subjective value of food rewards, but that these effects emerge with distinct temporal profiles. These findings provide important insight into when individuals may be susceptible to maladaptive choice behavior spanning addiction, anxiety and health behavior more generally.

3-E-15 The evil of banality: When choosing between the mundane feels like choosing between the worst

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Objective: Research has shown that our most important decisions tend to provoke the greatest anxiety, whether we seek the better of two excellent options or the lesser of two evils. Yet many of our choice are more mundane, between options we are less invested in, such as selecting from a slate of mediocre but acceptable restaurants. Intuitively these should not be anxiety-provoking. However, given that valuation is reference-dependent, it is possible that we can view below-average options as negative and that choices between them could then engender avoid-avoid conflict, experienced as aversive. While previous studies have exclusively found that low-to-moderate value choice sets decrease anxiety (e.g. Shenhav & Buckner, 2014), here we use a procedure that increases sensitivity to minimal value items and investigate how choices between such items are represented subjectively and neurally. Methods: Across three behavioral studies (Ns=20-26) and one fMRI study (N=30), participants evaluated their liking of common goods, having been encouraged to use the entire rating scale. They then made hypothetical choices between four-item sets, followed by retrospective ratings of the anxiety they experienced during each choice. In the fMRI study, choice trials were interleaved with trials where participants instead appraised the overall value of the choice set. Results: Across all four studies we found that anxiety ratings were greatest both when choosing between the highest value and lowest value choice sets (i.e., a U-shaped effect). We found that this effect can be accounted for by how strongly an individual wants or doesn't want the items in a set, consistent with a motivational salience account (relating to the strength of avoid-avoid or approach-approach conflict). We also demonstrate that this pattern is highly sensitive to the distribution of item ratings: excluding "zero-valued" items based on a willingness-to-pay procedure (as in previous work) artificially censors the lowest-valued items, making this quadratic effect look linear instead. Finally, we found the same salience pattern in brain regions that track choice anxiety (dorsal cingulate, anterior insula); importantly this neural pattern was specific to when participants were choosing (not when they instead appraised the overall set value). Conclusions: Collectively, our findings are consistent with the possibility that choice anxiety scales with the motivational salience of one's choice set, and that such sets can acquire negative value even when in the range of potential gains. They further highlight a surprising way in which valuation methodology affects interpretations of choice-related findings.

H – Individual & Lifespan Differences

3-H-16 Maladaptive personality traits are associated with cognitive control decision parameters: evidence from hierarchical Bayesian drift diffusion modeling

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Personality traits such as impulsivity and aggression are often framed in terms of poor decisions made

with limited evidence, yet process models of decision-making have rarely been applied to understand dysfunctional traits. Likewise, externalizing symptoms (e.g., reactive aggression) are central to personality disorders (e.g., borderline personality), but how such symptoms link to decision deficits remains poorly understood. In this study, we examined the association of maladaptive traits with interference control on an Eriksen flanker task using hierarchical Bayesian drift diffusion modelling (HDDM; Wiecki, Sofer, & Frank, 2013). The DDM is a computational model of two-choice decision tasks that represents speed-accuracy tradeoffs in terms of stochastic evidence accumulation (drift rate parameter) towards a decision boundary (parameter). Participants were 106 undergraduate students (69 female) who completed 160 trials of the flanker task. Participants also completed the Schedule for Nonadaptive and Adaptive Personality (SNAP-2; Clark, Simms, Wu & Casillas, 2007), an established broadband inventory of maladaptive traits composed of 12 trait scales and 3 temperament scales. Traits were incorporated as between-subjects predictors of decision parameters (drift rate or threshold) in DDM models of response time and accuracy on the flanker task. The relative evidence of trait effects on decision parameters was computed according to the deviance information criterion, comparing HDDM models with trait predictors versus baseline models in which only stimulus condition (congruent vs incongruent) affected DDM parameters. In general, models that allowed for trait x congruency interactions fit better than baseline models. In particular, we found that aggression, mistrustfulness, manipulativeness, exhibitionism, and disinhibition were most strongly associated with decision parameters. Overall, these externalizing traits were associated with higher drift rates in incongruent trials, indicating the tendency to accumulate evidence about a decision more quickly. Aggression and mistrustfulness were associated with reductions in decision thresholds across congruent and incongruent trials. Our findings illustrate the utility of fine-grained analyses of traits and decision processes to understand individuals with personality pathology. For example, aggressive and mistrustful individuals may tend to act on limited evidence, which may be linked to alterations in the mesolimbic dopamine system.

3-H-17 Individual Differences in Dopamine Receptor Availability Are Not Associated with Preferences for Time, Probability, or Effort Across Adulthood

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Some previous studies have reported age differences in decision preferences such that older adults are more willing to wait for delayed rewards. These data have been interpreted as evidence for motivational decline with age due to well-documented declines in dopamine (DA). However, there are few prior studies that have examined direct associations between measures of DA function and decision preferences in humans. Here we assessed preferences across multiple tasks and DA receptor availability using PET imaging in two samples of healthy adults. In study 1, 34 adults (ages 26-79) completed probability and time discounting tasks and a [11C]FLB457 PET scan. Preferences for sooner rewards were not correlated with DA binding potential in any brain region in the medial temporal lobe, temporal cortex, thalamus, parietal cortex, frontal cortex, or anterior cingulate, all $|r| < .07$, all $p > .679$. Similarly, preferences for higher probability rewards were not correlated with DA binding potential in any brain region, all $|r| < .16$, all $p > .36$. In study 2, 55 adults (ages 22-83) completed time, probability, and effort discounting tasks and a [18F]Fallypride PET scan. Preference for sooner rewards, all $|r| < .21$, all $p > .108$, higher probability rewards, all $|r| < .12$, all $p > .382$, or lower effort rewards, all $|r| < .18$, all $p > .190$, were not correlated with DA binding potential in any regions in the medial temporal lobe, temporal cortex, thalamus, anterior cingulate, or striatum. Age was not correlated with time, probability, or effort

preferences, all |r| < .22, all p > .061, in either study. Consistent with previous research, both studies showed DA binding potential declines with age in almost every region. However, our findings show that DA binding does not reliably correlate with discounting behavior. The present findings also suggest that age is not a strong predictor of discounting behavior. The present findings together are inconsistent with the recently proposed DA-based theory of motivational decline during decision making in older age.

3-H-18 Diminished fear of betrayal motivates cooperation in the elderly

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OBJECTIVES: Leaders in many organizations are seniors who routinely make decisions in social bargaining situations. However, we know little about how age influences strategic decision making. METHODS: Using a modified Prisoner's Dilemma game (PDG), we examined two important intrinsic motivations for non-cooperation: fear of betrayal and greedy desire to exploit other people among young and older Chinese Singaporeans. RESULTS: Results showed that compared with young adults, older adults demonstrated an intact greed motive but a diminished fear motive in the PDG. DISCUSSION: Our findings suggest that a diminished sensitivity to social threat motivates cooperation in older adults? social decision making. Older adults may have a declined ability to assess social threats even though they retain the motivation to gain exploitive advantage.

I - Intertemporal Decision-Making & Self-Control

3-I-19 Neural correlates of cognitive control as a function of emergent automaticity

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OBJECTIVE: Automaticity allows us to take advantage of environmental stability, enabling efficient deployment of well-learned responses to common stimuli. We must also, however, be prepared for the occurrence of infrequent events, since optimal outcomes in new conditions may require the deployment of cognitive control. A growing literature suggests that cognitive control may also benefit from experience-dependent automaticity, although the neural basis of this effect is not yet fully understood.
 METHODS: Using fMRI, we used a novel task to examine cognitive control in the face of an emergent automatic response. 24 participants performed a speeded response inhibition task where performance was incentivized by motivationally salient feedback and trials requiring inhibition were relatively infrequent.
 RESULTS: Performance in both frequent (i.e., not requiring control) and infrequent (i.e., requiring control) trials improved over time ($p<0.005$), although, as expected, performance was more accurate in frequent trials ($p<0.001$). Reaction time was also faster in frequent trials ($p<0.001$), but there was no significant reduction in response latency over time. Performance improvements in infrequent trials requiring control was accompanied by neural changes, with the right ventrolateral prefrontal cortex--a region implicated in response inhibition--demonstrating linear decreases in neural response over time ($p<0.05$, small-volume corrected).
 CONCLUSIONS: We found preliminary behavioral and neural evidence of automaticity in frequent as well as infrequent trials. These data are consistent with the theory that learning promotes behavioral and neural efficiency in cognitive control, even in environmental conditions when the need for control is rare.

3-I-20 The Repercussions of Concussions: Impact of Neurological Trauma on Temporal Discounting

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Objective: Research suggests that concussions may alter the decision-making of athletes who have

sustained concussions, specifically, the tendency to discount later rewards relative to immediate rewards, which may encourage repeated concussions. Previous literature has indicated a correlation between brain trauma and discount rates in a clinical sample (Wood & McHugh, 2013). The objective of this study was to illuminate the relationship between concussions and temporal discounting in a non-clinical sample of athletes and former athletes. This group is at particular risk of both TBIs and sub-concussive head impacts. We hypothesized that length of participation in a high-impact sport (football), in addition to the number of concussions one has been diagnosed with, will positively predict overall discount rate. Methods: We recruited 228 college-aged (17-24 years) athletes and former athletes from New York, Colorado, Minnesota, Kansas, and New Jersey to complete an online questionnaire assessing self-reported athletic and concussion history, the 27-item Monetary Choice Questionnaire (MCQ; Kirby, Petry & Bickel, 1999), UPPS-P Impulsive Behavior Scale, Barratt Impulsiveness Scale, Hoyle Brief Sensation Seeking scale, as well as risk taking. Results: Discount rate correlated positively with the number of diagnosed concussions in the past year, but not with number of diagnosed concussions in the subject's entire life. Simultaneous regression was used to assess unique predictors of discount rate. Significant predictors included: years played in American football, the number of times diagnosed with a concussion in the past year, and a sensation seeking/impulsivity factor. These predictors all positively predicted overall discount rate, while controlling for age, sex, whether the participant was an athlete or former athlete, and self-reported history of concussion diagnoses over the lifespan. Conclusions: As expected, concussions were associated with greater discounting, suggesting that diffuse brain trauma increases impatience, controlling for individual differences in impulsivity. Years playing football also predicted greater discounting, controlling for lifetime and recent concussions, suggesting effects of sub-concussive hits routinely associated with student sports. These results with nonprofessional athletes outside a clinical context echo those with clinical populations, but they raise concerns that ordinary exposure to brain trauma may impair temporal decisions.

3-I-21 Is Toxoplasma gondii infection related to time and risk preferences of humans? Some evidence for manipulation hypothesis

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The aim of this study was to ascertain the influence of the parasite Toxoplasma gondii infection on risk and time preferences of humans. Toxoplasma gondii is a protozoan parasite that causes toxoplasmosis which is spread among approximately one third of the human population, including developed countries. In its latent phase, the disease is clinically asymptomatic, nevertheless, Toxoplasma gondii can influence the nervous and endocrine system of its hosts. Extensive evidence proves that toxoplasmosis relates to many psychiatric disorders, changes in personality traits and some aberrant behavior in humans. We used data from a questionnaire survey (N≈1600) which included information on the infection status of the respondents and their responses to hypothetical decisions that elicited risk and time preferences. We were also able to control on the demographical, economical and health covariates for most of the respondents. We found out that infected individuals show more patient behavior than the uninfected; this relationship is however not as robust in some model specifications. The relationship is also mediated by Rh blood group, as previous studies have indicated. Influence of toxoplasmosis on risk preference was not supported by the data. In the conclusion, we discuss the limitations of this study, especially the problem of selection of specific groups of respondents into the questionnaire survey.

3-I-22 Midfrontal theta and pupil dilation parametrically track subjective conflict (but also surprise) during value-guided choice

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During perceptual and sensory-motor decisions, the medial prefrontal cortex (mPFC) supports conflict and action monitoring processes, and the locus coeruleus-norepinephrine system (LC-NE) regulates arousal and neural gain. Many everyday choices, however, do not have objectively correct responses and require individuals to assign a subjective value to each available choice option and then choose the option with the highest value. It remains unclear whether the mPFC and LC-NE systems track subjective conflict during value-guided choice, and if they discern even fine differences in subjective value. In this pre-registered study, we used an economic model to manipulate eleven different levels of subjective conflict during an intertemporal choice task by presenting participant-specific, model-derived delayed rewards. We concurrently recorded electroencephalographic (EEG) data and pupil dilation responses to investigate mPFC and LC-NE system activity respectively. Midfrontal theta power, derived from EEG, correlated with pupil dilation responses, and as predicted, these signals tracked even fine gradations of subjective conflict, extending previous work that compared only high versus low objective conflict. Unexpectedly, however, both signals were also maximally enhanced when decisions were surprisingly easy. We suggest, therefore, that these signals track events that require increased attention and adaptive shifts in behavioral responses, with conflict being only one type of such event. Our findings suggest that the mPFC and LC-NE neuromodulatory signals interact to engage flexible and adaptive control processes such as neural gain modulation that optimize decision making.

3-I-23 Recent and imminent heroin use is reflected in recruitment of prefrontal cortex in intertemporal choice

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Objective: Increased impulsive decision-making has been widely observed in individuals with substance use disorders. Several studies have pointed to brain regions in the valuation network as necessary computational neural substrates for this behavior, and posited that dysfunction in this circuitry in drug users, as compared to controls, might be at the basis of these disorders. Although identifying these regions is important, more pressing and clinically relevant questions remain unanswered: how does this dysfunction relate to the severity of drug use? And, in the case of treatment-seeking individuals, how does it relate to treatment success/failure, i.e. concomitant use, relapse and dropout? Focusing on the current opioid epidemic, we addressed these questions by following a cohort of patients with Opioid Use Disorder (OUD) starting standard-of-care treatment, and assessing their neural activity in a temporal discounting (TD) task at 2 time points over the course of their treatment. Critically, this longitudinal approach allowed us to follow their dynamics in symptomatology, drug use and impulsivity and test how our neural measures relate to recovery or treatment failure. Methods: We conducted 2 fMRI sessions in OUD patients starting standard outpatient treatment (~4 and ~12 weeks post treatment entry). Patients completed a TD task in the scanner in which they were asked to choose between immediate and delayed monetary rewards. Patients' symptoms, drug use (by self-report and toxicology) and impulsive decision-making were assessed during the fMRI sessions and in multiple separate sessions over the course of 7 months. fMRI and behavioral testing was also performed in a cohort of matched community controls (CC). Results: We find similar task-based activation of valuation circuit areas, e.g. ventromedial prefrontal cortex and posterior cingulate cortex, across both OUD patients and controls (n=10 OUD group, n=8 CC group). Interestingly, in OUD patients, dorsolateral prefrontal cortex (DLPFC) subjective value coding for delayed rewards decreased as a function of both recent and imminent heroin use. Conclusion: Our results point to a role for DLPFC recruitment during intertemporal choice as a contributor to treatment

success, and suggest it could be a potential candidate area for therapeutic intervention. Current efforts in this study focus on evaluating whether individual changes in discounted subjected value coding across the 2 time points map to each patient's clinical trajectory, and establishing whether neural activity elicited by our task is truly predictive of future drug use, relapse and dropout from treatment.

3-I-24 Investigating the role of perspective-taking in intertemporal decision-making

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A key step in making intertemporal choices, between rewards now or later, is imagining how much we will enjoy the later reward. Emerging data suggest we subjectively value future rewards by taking the perspective of our future selves using the social abilities used to take the perspectives of others (Soutschek et al., 2016, Sci. Rep.). To explain this effect, the Simulation-based Model of Intertemporal Preferences (SMIP) proposes that the control of egocentric bias, which helps shift away from self and towards other people's perspectives, also promoting preferences for delayed rewards during intertemporal choices by enabling us to shift away from the immediate perspective towards future ones (O'Connell et al., 2015, Front. Neurosci.). This positive relationship between egocentric bias control and future reward preferences was tested in two studies. In Study 1 (n=90), participants performed a visual perspective-taking task and a temporal discounting task. A positive correlation was found between abilities to control egocentric bias and preferences for future rewards (r=.36), replicating the effect of Soutschek et al. (2016). In Study 2 (n=36), subjects were scanned using functional magnetic resonance imaging while they made intertemporal choices, and completing a false-belief task which required the control of egocentric bias. A positive correlation was observed between people's activity in the right temporoparietal junction (rTPJ) during egocentric bias control and their preferences for delayed rewards (r=.32). This same rTPJ region involved in egocentric bias control (localized separately in individuals during the false-belief task) was also found to be recruited more during delayed versus immediate choices (p=.025). Lastly, functional connectivity between this rTPJ region and processes involved in valuations of future reward in the ventromedial prefrontal cortex (vmPFC) was dependent on intertemporal preferences, suggesting the contribution of processes related to egocentric bias to these decisions. The current results support the involvement of egocentric bias control in determining preferences in intertemporal choices as hypothesized by the SMIP, and point toward a social cognitive explanation for why rewards are devalued with delay in temporal discounting.

3-I-25 Modeling of Preference Reversal in a Temptation Task

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There has been a debate about the neural basis of intertemporal decision-making. Two main types of models have been proposed: Single and Dual System models. Single System models suggest that agents make their choice by directly comparing the value of options, using the output of a single evaluation system based on the magnitude of reward and length of delay, without an additional cognitive process such as self-control. On the other hand, Dual System models suggest that two different systems evaluate the value of options. One operates over a short time horizon, while the other operates over a long time horizon. In this case, delay of gratification depends on the ability of the far-sighted evaluation system to suppress the short-sighted system. This form of self-regulation is called self-control. To investigate this question, we designed an experiment that dissociates the possible effect of self-control from reward magnitude and delay. This allowed us to examine how changes in the level of self-control affect choice behavior, as well as to identify neural activity that is correlated with changing levels of self-control. In this experiment, monkeys had to choose between a smaller-sooner and a larger-later reward option.

Normally, they received the chosen reward after the indicated delay. However, in a minority of 'temptation' trials, after making the decision, the alternative option remained available and monkeys had the chance to change their choice. Results in two monkeys showed a significant preference shift toward sooner rewards in temptation trials. These findings indicate that monkeys often do not maintain their initial preference for larger, but more delayed reward in the presence of smaller, but more immediate reward. Statistical analysis indicated a significant difference in chosen delay between initial and final decisions. We also tested, if a Single System model can explain our behavioral findings. We fitted a hyperbolic discounting model to the initial choices and used it to predict the subsequent final choices on temptation trials. The model could not predict the observed proportion, direction and timing of switching behavior. Since a simple uniform hyperbolic evaluation model could not explain this switching behavior, it seems necessary to include self-control as an effective factor in decision-making.

3-I-26 Intertemporal Choice and Subjective Reference Point

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There is a growing evidence that personal goals can affect people's choice, similarly to the status quo as reference point. However, little is known how personal goals affect to people's intertemporal preferences. Thus, we investigated, how the personal salary expectation affected to the intertemporal preference, when the amount and time of the offers varied. This paper presents behavioral data of 19 healthy, right-handed students (7 males, mean age: 28.3 years; range: 20.7 - 39.1), who participated in the fMRI-study. The ethics committee of the Hospital District of Helsinki and Uusimaa approved the study. The subjects gave their written informed consent before participating. Before entering the scanner, the subjects were asked for their personal wage expectation. The wage offers were scaled according to this subjective reference point during the fMRI-experiment. Participants were exposed to a series of wage offers on the screen in which they were asked to choose over a series of two option choice-sets. The amount of Now-Option (NO) was always lower than Later-Option (LO). The time difference was 0.5, 1 or 2 year. There were four types of offers: both NO and LO were below personal reference points, NO were below reference point and LO were reference point, NO were reference points and LO were above reference point and finally, both NO and LO were above reference point. The order, the delays and the absolute amounts of wages were varied. Each participants got 216 offers in randomized order. We calculated k-value for each participant and for all four types of offers. We used hyperbolic discounting function v/(1+k*t), where v is immediate value and t time. Hyperbolic discounting function was fitted independently for each subject and condition by using the logistic function 1/(1+exp(â*dx)), where dx is k-dependent discounted difference and the â slope parameter. We then compared k-values of different offer types using paired Wilcoxon signed rank test and Friedman's test. We found that the offer type had a statistically significant effect on k-values (Friedman's test; $p < 0.001$). Fitted k-values were highest (Mdn = 0.186) with type 1 offers and lowest with type 4 offers (Mdn = 0.121). Median difference between type 1 and type 2 was 0.060 (Wilcoxon signed rank test; $p < 0.01$); 0.049 between type 1 and 3 ($p < 0.05$); 0.065 between type 1 and 4 ($p < 0.001$). Also the median difference between types 3 and 4 was 0.016 ($p < 0.01$). We showed that intertemporal preferences vary in both individual and group level according to the subjective reference point. The study broadened previous findings about the critical role of the subjective goal to human behavior to the intertemporal choice.

3-I-27 Effort and Delay Discounting in a Foraging Environment

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Introduction: Many decisions require weighing the value of an outcome against the cost of obtaining it. Monetary cost, cognitive effort, and time delay all detract from the net value of prospective rewards. Here we examined the relative cost of cognitive effort and delay in the context of foraging behavior. Methods: In a between-subject design, participants foraged for rewards in an environment that required either cognitively effortful responding (n=11) or an equivalent unfilled delay (n=11). Participants could earn points on each trial, or could quit anytime the perceived opportunity cost outweighed the delayed reward. Trials differed in the reward amounts on offer and in the amount of effort or delay necessary to obtain rewards. Results: We hypothesized that all participants would be less likely to accept low-reward and/or long-delay trials, and that the cognitive effort group would accept fewer trials overall (reflecting a greater perceived opportunity cost). Results supported the first hypothesis. However, contrary to the second hypothesis, the cognitive effort group accepted significantly more trials, while earning less overall than the delay group. The cognitive effort group approximated reward-maximizing behavior during short-delay trials, but over-accepted during longer delays. Conversely, the delay group better approximated optimal performance when the delay was long, but under-accepted otherwise. A similar pattern held across reward amounts: the cognitive effort group over-accepted low and medium rewards, whereas the delay group under-accepted them. Most decisions to quit occurred within 1 s of the start of the trial (there was little delayed quitting). Behavior changed little over the course of the experiment, suggesting participants formulated their strategy rapidly. We used a softmax decision rule to model each participant's probability of accepting a trial based on the difference between the delayed reward and the estimated opportunity cost (a free parameter). The cognitive effort group had significantly smaller opportunity cost estimates than the delay group, implying that cognitive effort was perceived as less costly than an equivalent unfilled delay. Conclusions: Our results are at odds with previous findings on the aversiveness of cognitive effort, suggesting instead that effort can boost the apparent subjective value of delayed prospects. One possible explanation is that participants in the cognitive effort group found value in the cognitive tasks (i.e. learned industriousness). Another possibility is that concurrent cognitive effort altered the perception of time-interval durations.

J – Learning & Memory

3-J-28 Short-term plastic changes in the primary sensory cortex elicited by monetary outcomes

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The dominant neurobiological models of decision-making assume that sensory inputs to decision-making neural networks are stationary. However, many cognitive studies have demonstrated experience-induced plasticity in the primary sensory cortex. This suggests that repeated decisions may modulate sensory processing. In our study, we tested the hypothesis that a repetitive association of a stimulus with a monetary outcome during a monetary incentive delay (MID) task may lead to changes in plasticity in the primary sensory cortex. We designed an auditory version of the MID task (Knutson et al., 2001, 2000), in which the subjects were punished, based on their responses to a cued, target stimulus. For each trial, the subjects (n = 30) were exposed to one of six "acoustic incentive cues", depicting the monetary contingency of that trial: a small or large potential monetary loss (or break-even). Importantly, in control conditions, the subjects' discrimination of the incentive cues was task-irrelevant. Overall, the subjects participated in two extensive sessions of an audio-version of the MID-task on two consecutive days. We investigated electrophysiological correlates of the experience-induced plasticity of the primary auditory cortex by comparing the mismatch negativity (MMN) evoked by six incentive cues, before and after MID-task sessions. The MMN is an electric brain response, which is automatically elicited by any discriminable

change in repetitive sounds or sound patterns. We used a "roving" MMN paradigm to ensure that the MMN changes were entirely due to perceptual learning and could not result from differential states of frequency-specific auditory neurons in the temporal cortex. Following the subjects' extensive MID-task training, we found that the expected monetary loss evoked the significant MMN-amplitude enhancement (the negative deflection increased from -0.56 μV on the first day to -1.6 μV on the second day, Cz, $p < 0.05$), which may reflect a fine-grained stimulus discrimination of stimuli that predicts financial losses. This change in MMN was absent in the control condition. In conclusion, our results demonstrate that a repeated MID-task evokes short-term, plastic changes within the auditory cortices associated with improved stimulus discrimination and involuntary attention toward auditory cues that predict significant monetary losses. The study was supported by the grant 16-18-00065 of the Russian Science Foundation.

3-J-30 Using reward to extinct fear

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Previous research has shown that fear extinction can be enhanced by simultaneous presentation of two aversive cues, also referred as compound extinction. However, introducing two aversive stimuli at a time might lead to a greater suffering, reducing therapy success. In this experiment, we investigated 1) whether simultaneously presenting appetitive cue, together with aversive cue (appetitive-aversive compound extinction) can induce similar fear-reducing effect as aversive-aversive compound extinction, and 2) its underlying behavioral and neural mechanisms. Healthy male subjects were invited twice. On the day I, the participants underwent a simple cue-outcome association learning (both cue-shock and cue-reward) followed by single and compound extinction. One week later, the extinction success was tested by reinstatement. The extinction degree of the shock cues were assessed by subjective pleasantness ratings. Our preliminary results on pleasantness ratings show that the appetitive-aversive compound extinction successfully reduces fear to a comparable degree as aversive-aversive compound extinction. Furthermore, the noappetitive-aversive compound extinction did not lead to a significant decrease in fear responses during reinstatement, indicating that appetitive-aversive interaction during compound extinction may be driven by salience. These findings open the door to a new potential way reducing the fear relapse by introducing reward during extinction.

L - Risk & Uncertainty

3-L-31 The battle for self-confidence: a tug-of-war between prospective gains and losses

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When estimating their chances of succeeding at a task or a project, healthy people tend to exhibit a desirability bias: they are inclined to perceive as relatively more likely events that are desirable. More specifically, the more desirable the outcome attached to a success (the higher the potential benefit), the more confident people are in their chances. Several interpretations have been suggested to such phenomenon. The rosy-outlook hypothesis simply postulates that people distort their confidence judgment, in proportion to potential benefit, to feel better about their future, and avoid stress or anxiety. The motivational reasoning hypothesis assumes that people intend to adjust their resources depending upon the potential benefit: 'There is a lot to win here, therefore I will try harder at the task, therefore I'm more likely to succeed.' In any case, the notion of desirability bias implies that confidence judgments should correlate positively not only with prospective gain in case of success, but also with prospective loss in case of failure, because the perspective of avoiding larger losses also makes success more desirable. However, recent findings in decision neuroscience would yield a different prediction. The

same brain region (namely, the vmPFC) was found to represent both the likeability of various stimuli and confidence in the selected response (probability of success). Moreover, some spillover effects, such as the impact of background music on painting evaluation, may be mediated by changes in vmPFC baseline activity. This contamination mechanism could be extended to a contamination of confidence judgments by outcome values: confidence would follow vmPFC baseline, being positively biased by prospective gains and negatively biased by prospective losses. In order to disentangle between desirability bias and contamination mechanisms, we conducted a series of 4 behavioral experiments, where participants rated their confidence prior to performing a motor precision task. Critically, we varied both the expected gain associated to success, and the expected loss associated to failure. We observed that confidence ratings were positively correlated with gains and negatively correlated with losses, as predicted by the contamination mechanism. Importantly, these distortions of confidence judgments were dissociated from the actual performance (success rate), which was not affected by expected gains and losses. Thus, our findings challenge the notion of desirability bias and suggest instead a contamination mechanism through which the value of any contextual feature may bias confidence judgment. This might be a consequence of the functional properties of the vmPFC, which we are presently investigating using fMRI.

3-L-32 Understanding risky social contexts: increasing and decreasing human risk tolerance

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Objective We aim to understand how two sources of social influences modulate participants' risk preferences. We used the Balloon Analogue Risk Task (BART), which has shown to identity adolescents at risk for harmful activities, to decompose social modulation of risk preferences into contexts shaped by beliefs about the likely behaviors of others, and from direct interaction. Methods Participants in the BART pump a balloon to accumulate tokens and aim to cash in these tokens before the balloon pops. In social contexts, two participants, each with their own balloon, play simultaneously and besides not popping their own balloons, should cash in higher than their opponent to secure their cashed tokens. In the belief only context, the identity of the opponent was known, but actions during play were hidden. In the interaction only context, opponent identity was hidden, but balloon pump actions were visible in real-time. To measure participants' beliefs about balloons' pop point and their opponents' behavior, we introduced a novel belief elicitation task. We conducted functional magnetic resonance imaging (fMRI) on 29 participants as they played the BART alone and in social contexts while interacting in real-time with other participants who were seated in a behavioral laboratory. Results Participants' behavior was substantially influenced by social contexts. In the belief only context participants increase their willingness to take on risk (compared to playing alone) by pumping the balloon an average an additional 6 times. In the interaction only context, participants decrease the average number of pumps (2.5 less). However, the average interaction-only behavior does not tell the complete story. Participants show a preference for pumping to a similar level as their opponent, pumping less when the opponent ends at a lower number and more when the opponent pumps higher. FMRI analyses provide support for separate neural mechanisms underlying social belief and direct interaction. Although both contexts activate theory of mind regions, the belief only context shows a more pronounced activity pattern in frontal medial regions, whereas the interaction only context activates lateral components of brain areas associated with social processing. Conclusion Participants' risk preferences are influenced by social contexts, demonstrating social modulation of risk preferences that can both increase and decrease tolerance for risk as compared to behavior alone. These behavioral differences are supported by separable neural mechanisms which together provide clues for how social factors influence risk preferences in social situations.

3-L-33 fMRI Investigation of Uncertainty Attitudes and PTSD Symptom Severity in Combat Veterans

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Objective: Traditional research of trauma-related psychiatric disorders often focused on emotion regulation, such as fear learning in PTSD (Posttraumatic Stress Disorder). Our study tries to approach this disorder from a different and often-neglected aspect of trauma-related symptoms, individual differences in uncertainty attitudes. Uncertainty is especially important in studying PTSD in combat veterans, due to high levels of uncertainty surrounding traumatic experiences in the battlefield. We have successfully used behavioral economics to identify markers of PTSD by measures independent of the pathology itself (Ruderman et al., 2016), and found that PTSD veterans were more averse to ambiguity (unknown outcome probabilities), but not risk (known probabilities), compared to control veterans, when choosing between losses, but not gains. Here, we explore the neural markers of symptomatology by the same task, with the advantage of eliminating potential biases related to self-report or re-experiencing of trauma. Methods: We studied 47 combat veterans (20 with current PTSD, 18 controls, and 9 with past but not current PTSD) to assess their risk and ambiguity attitudes in a monetary task. Subjects chose between a guaranteed win (or loss), and playing a lottery which offered a larger gain (or loss) but also chance of zero outcome. Outcome probabilities for half of the lotteries were precisely known, and were ambiguous for the other half. Functional MRI was used to track neural activation while subjects completed 240 decisions. One choice was randomly picked for payment. Results: We replicated our recent behavioral result that veterans with PTSD were more averse to ambiguity under losses ($p<0.05$). Interestingly, past PTSD veterans were not averse to ambiguous losses, and behaved more similarly to controls. Neurally, overall activation in vmPFC, an area involved in value-based decision making, was negatively correlated with overall PTSD symptom severity (by Clinician-Administered PTSD Scale [CAPS]; $p<0.05$ under both ambiguous gains and losses), as well as symptom severity of emotional numbing (by the 5-factor model of CAPS; $p<0.05$ under ambiguous gains). We also found an unexpected trend of stronger representation of subjective value in vmPFC, ventral striatum and ACC, in PTSD patients compared to controls, suggesting a potential resiliency marker in controls. Interestingly, although our task is not trauma-related, these same brain regions have been previously implicated in fear-learning of PTSD. Conclusions: Our results demonstrate the potential of neuroeconomic techniques for studying psychopathology in terms of basic cognitive function, and for devising objective diagnostic tools that compensate the insufficiency of DSM based categorical diagnoses.

3-L-34 Risk Attitude as a Perceptual Bias

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A unified theory of random variation in choices between risky prospects, and departures from risk-neutrality (in both directions), is proposed, paralleling an explanation that has been offered for both stochasticity and bias in perceptual judgments, including judgments of numerosity. According to this view, both the randomness of choices and the average bias result from the fact that choices must be based on a noisy internal representation of the decision situation, rather than on an exact description of it. Noise in the coding of the data that define the problem results in stochastic choice (conditional on the true situation), and an optimal decision rule (from the standpoint of expected wealth maximization) implies behavior that (from the standpoint of an experimenter who knows the true data) appears to

violate risk-neutrality. Our assumed model of noise in the coding of potential monetary payoffs is furthermore consistent with evidence on how discrimination thresholds, biases in average estimates, and the variability of estimates across trials scale with increasing stimulus numerosity in the case of numerosity perception. Our experiments document both randomness in subjects' choices when presented repeatedly with the same risky prospects, and the "fourfold pattern of risk attitudes" reported by Tversky and Kahneman. A computational model with only three free parameters (indicating the degree of noise in the internal representations of risky monetary payoffs, certain monetary payoffs, and probabilities, respectively) suffices to allow joint prediction of several hundred moments of the experimental data, characterizing both the average biases in choice in different cases and the degree of variability in choices across trials. It thus provides a functional explanation for several of the main non-normative aspects of behavior summarized by prospect theory, linking them to the need to economize on the neural resources used to represent numerical magnitudes when evaluating risky prospects. The theory also predicts new phenomena (notably, payoff-magnitude-dependence of the apparent distortion of probabilities) not predicted by prospect theory, but confirmed in our experimental data as well as other studies.

3-L-35 How brain rhythms code for variables of decision making: EEG motor beta oscillations reflect reward and risk level associated with an action

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Objective Choosing a course of action in our daily lives requires an accurate assessment of the associated risks as well as the potential rewards. We investigated the neural dynamics of this process by focusing on the neural oscillation patterns reflected in the EEG signals. In particular, we determined whether the beta frequency oscillations involved in motor processing are modulated by the reward and risk level associated with an action. Methods Participants performed a modified version of the Go-NoGo task, in which they earned rewards based on speed and accuracy. The trial started with a presentation of the reward points at stake (high vs. low) and the probability that a Go signal would follow (Go-probability) (trial information period). A Go/NoGo signal was presented afterwards. Faster responses gave larger proportion of the rewards at stake, whereas false alarm resulted in deduction of rewards. EEG was recorded throughout the task. We compared the magnitude of beta desynchronization/synchronization across different reward and Go-probability conditions in the contralateral and ipsilateral motor cortex and the right inferior frontal cortex (rIFG), the brain regions known to be involved in motor initiation/ inhibition. Results During trial information period, we found a significant reward by Go-probability interaction in the contralateral motor cortex. Greater beta desynchronization was found in high compared to low reward condition with high Go-probability. When the Go-probability was low however, indicating greater risks associated with a Go response, beta desynchronization was greater in low compared to high reward condition. No such effects were found in the ipsilateral motor cortex or in the rIFG. After the onset of the Go/NoGo stimulus however, there was a significant effect in the rIFG which is known to be involved in "reactive stopping". Greater beta synchronization was found in high compared to low reward condition with high Go-probability while no such difference was found with low Go-probability. This suggests a greater involvement of the reactive stopping mechanism when changes are required to the prior motor plans. Importantly the power of beta frequency oscillations from the motor cortex and rIFG predicted the response time and false alarm rate, suggesting that changes in beta oscillations across different reward and risk levels reflect how these decision variables shape the motor system which lead to a Go vs. NoGo response. Conclusion Our results suggest that brain rhythms involved in movement planning can code for the expected value of an action by integrating reward and

risk level associated with an action. These results provide a mechanistic understanding of how decision variables can guide choice for an action.

3-L-36 Reconsidering the description-experience gap: Overweighting of rare events in experienced-based decision under risk

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Accumulating evidence indicates that, in decision under risk, people tend to distort information about probability associated with potential outcomes. The pattern of distortion tends to change depending on how probability information is revealed to the chooser. When probability is explicitly described to the subjects, subjects tend to overweight small probabilities but underweight moderate to large probabilities. In contrast, when information about probability is acquired through experience, the opposite pattern of distortion was observed (Hertwig et al., 2004). This is often referred to as the description-experience gap. Hills and Hertwig (2010) found that subjects' sampling strategy in the experience-based task affected probability distortion -- subjects who switched more often between lotteries during sampling exhibited larger underweighting of small-probability events. To directly test the impact of switch frequency on probability distortion, we manipulated the switch frequency and randomly assigned subjects to either the high or low frequency condition. We hypothesized that more underweighting of small probability would be observed in the high switch-frequency condition. Another goal of our experiment is to investigate whether subjects will violate the independence axiom of expected utility theory (EUT) in experience-based decision making. Violations of the independence axiom have been attributed to probability distortion and patterns of violations can be used to infer the shape of the probability weighting function. Utilizing the design in Wu & Gonzalez (1996), we tested the independence axiom in experience-based decision making and estimated the probability weighting function. Analysis of choice data of individual subjects showed that people significantly violated the independence axiom in the high switch-frequency condition (N=86), but not in the low switch-frequency condition (N=49). Surprisingly, based on the pattern of violation, we inferred that subjects overweight small probabilities and underweight large probabilities in the high frequency condition. These results indicate that while switching frequency can affect probability distortion, subjects in experience-based task distort probability similarly to what had been shown in decision from description.

M - Social Rewards & Social Preferences

3-M-37 Characterization of selfish behavior in a modified dictator game

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Objective: Social preferences vary, with some individuals demonstrating excessive selfishness in their choices to share resources with others. The independent roles of affective and cognitive empathic deficits, and associated psychopathic and narcissistic traits, has not been well-characterized beyond simple donation paradigms. Methods: The current study examined the roles of empathic traits in generosity and inequity aversion in an incentive-compatible modified dictator game (DG), in which participants decided unilaterally how to split a sum of tokens with another participant and exchange rates varied across trials from 3:1 to 1:3 (tokens were worth up to three times their monetary value if kept or passed, respectively). Adult participants across the United States recruited via Amazon Mechanical Turk completed the modified DG, commons and prisoner's dilemmas, and self-report measures of personality traits. For the DG, in addition to mean generosity and inequity, parameters for aversion to advantageous and disadvantageous inequity were computed for each participant based on choices across twenty trials. Results: Trait affective empathy independently negatively predicted

generosity and inequity, while trait cognitive empathy did not. In contrast, both psychopathic and narcissistic traits independently negatively predicted generosity and inequity, particularly the coldheartedness aspect of psychopathy. Aversion to advantageous inequity was associated with affective empathy (but not cognitive empathy), narcissism, coldheartedness, and selfish behaviors in the commons and prisoner's dilemmas. Disadvantageous inequity aversion was not associated with these personality traits or behaviors. In the DG, approximately half of the sample engaged in decisions that resulted in disadvantageous inequity, whereas all but a few participants engaged in decisions that resulted in advantageous inequity. Participants who created disadvantageous inequity scored lower on narcissistic and coldhearted traits, and higher on trait affective empathy. Trait cognitive empathy did not differentiate between these participants. Conclusion: This study builds on prior work by demonstrating the independent contributions of aspects of empathic traits to computationally-characterized selfish social preferences. Specifically, results highlight that self-reported trait affective empathy may be a better predictor of excessive selfishness than self-reported trait cognitive empathy, and both psychopathic and narcissistic traits independently predict excessive selfishness in a non-clinical sample.

3-M-38 Cognitive Processes of Prosocial and Antisocial Punishment

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This paper investigates the cognitive process underlying prosocial and antisocial punishment using response time and choice data from a public goods game. The results show that response time decreases with the strength of preference on punishment or non-punishment, which indicates that both the cognitive process of prosocial and antisocial punishment complies with sequential sampling models. In addition, the sequential sampling process starts near the threshold of non-punishment when cooperators punishing defectors, and the process starts near the threshold of punishment when defectors punishing cooperators. That is, prosocial punishment is more deliberative and antisocial punishment is more intuitive than non-punishment. Furthermore, the sequential sampling process of punishment can be corroborated by the response time difference between punishment and non-punishment. And the intuition or deliberation of punishment can be corroborated by out-of-sample predictions.

3-M-39 Computational phenotyping using a social hierarchy probe

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Introduction: Borderline Personality Disorder (BPD) and Anti-Social Personality Disorder (ASPD) are psychopathologies characterized by profoundly aberrant interpersonal behaviour that strongly affect the lives of both individual patients and those around them. BPDs and ASPDs share many behavioural characteristics, such as impulsivity and difficulty in sustaining long-lasting social relationships, and although they are considered different disorders, the distinction between them is sometimes blurred. One notable distinction is the manner of interpersonal interactions, with ASPD patients tending to exploit others, whereas BPD patients tend to be exploited themselves. However, this distinction has yet to be fashioned into a quantifiable psychometric instrument. Methods: Here, we have participants play a multi-round Social Hierarchy decision-making paradigm (119 controls, 219 BPDs and 23 ASPDs), and applied computational models to the obtained behaviour. Results: We found that ASPD participants, when playing the Social Hierarchy game, gave significantly less to the other player when compared to Controls and BPDs. Furthermore, ASPDs challenged more, were in the dominant position more often, used more money to defend their alpha position, and left their opponent with lower final earnings compared to BPDs and Controls. BPDs, on the other hand, gave more to the other player compared to

both ASPDs and controls, and left their opponent with more money. Indeed, BPDs were the only population of the three for whom both the participant and their opponent finished with the same final earnings. A logistic regression model relating the decision to challenge to the transfer amount indicated further differences between the populations: BPDs' decisions to challenge seemed more sensitive to the amount of money transferred by the opponent as compared to controls, while for ASPDs the opposite pattern was observed. We are also developing a reinforcement-learning computational model that takes into account inequity aversion (both guilt and envy), as well as an intrinsic value for dominance and a drive to remain in charge (alpha). Discussion: Our results suggest that ASPDs are less prosocial and value social dominance more than healthy controls and BPDs, whilst the latter are particularly sensitive to social signals, and offer specific computational parameters that can be used to quantitatively characterize and phenotype each individual. These results open promising avenues by which different psychiatric disease states could be characterized and distinguished at the mechanistic level, and offer a tool by which to benchmark different treatment outcomes.

3-M-40 How significant others' opinions affect one's own shopping decisions? An fMRI study on college couple shopping

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In our everyday lives, one of the easily observed phenomena is the dependence on important others? opinion in shaping our decisions. Along with the growing interest in social neuroscience, the current fMRI study observes college young couples? (together for over one year) interactive shopping behaviors. In the behavioral phase, 22 couples were recruited from NCKU campus, and were familiarized with the interactive shopping task. After the fixation cross of each trial, one product was presented along with price underneath to two connected computers. In the ?together? condition, two outpointing arrows adjacent to the fixation cross indicated that before one?s purchasing decision, the significant other?s opinion would be revealed; whereas two inwardly pointing arrows next to the fixation representing that only one?s own preference rating was shown. Participants gave preference rating from 1 (dislike most) to 4 (like most) to each product. The computer screens would show either own rankings or own-plus-other rankings (on both sides of the product), and then the purchasing decision was made under each condition. In the subsequent fMRI sessions, the task setting was identical (except for different stimuli), and 30 participants underwent fMRI for 4-5 runs (24 trials each). The results showed (a) the more one likes the product, the higher probability that one will purchase it. And this tendency is coded (using parametric modulation) in ventromedial prefrontal (vmPFC) area; (b) the modulation of the romantic relationship on one?s own buying decision was also obvious: compared to making the decision ?alone?, people?s shopping decisions were clearly modulated by the preference of significant other's ratings: if the significant other likes it, one?s shopping tendency increases, whereas the disliking of significant other?s ratings also weakened one?s own willingness to buy. The neural activity at the time of buying decision between ?together? and ?alone? contrasts revealed regions in Temporal Parietal junction (TPJ) and anterior insula, typically associated with the theory-of-mind (TOM) processing. (c) the psychophysiological interaction (PPI) analysis with the rTPJ as seed also revealed that, between the ? incongruent (one button 34 vs. the other button 12, or vice versa)? vs. ?congruent (both pressed 34 or 12)? trials: caudate, insula, anterior cingulate, and the medial prefrontal area showed higher connectivity in the former condition. Together, these results strongly demonstrate, with the two-person interactive fMRI, the importance and neural underpinnings of how significant other's opinions modulate one?s own shopping decisions.

3-M-41 Ideal affect match promotes trust

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What promotes trust in strangers? Our previous research suggests that people share more with others based not on similar race or sex, but rather based on the perception of shared ideal affective states, or "ideal affect match." Since culture shapes ideal affect (e.g., European Americans want to feel excited whereas East Asians want to feel calm), this suggests a means by which culture can influence resource allocation. Here, we sought to extend these findings to determine whether ideal affect match can increase trust in strangers. Thus, we asked 48 European Americans and 52 Koreans to play multiple trials of a Trust Game with potential trustees whose faces varied with respect to emotional expression (excited, calm), race (White, Asian), and sex (male, female). Consistent with cultural differences in affect valuation, European Americans transferred more to trustees with excited smiles than calm smiles, whereas Koreans transferred more to trustees with calm smiles than excited smiles. These findings held regardless of trustees' race and sex. Moreover, European Americans expected excited trustees to return more money, but Koreans expected calm trustees to return more money. These cultural differences in transferred amount of money and expected return were mediated by differences in ideal affect and ratings of perceived trustworthiness of the trustees. Specifically, European Americans wanted to feel excited states more, which made them perceive excited trustees as more trustworthy than calm trustees, which facilitated increased monetary transfer to excited vs. calm trustees, and led them to expect more money from excited vs. calm trustees. Their Korean counterparts showed the opposite pattern of findings. Ongoing neuroimaging work will test whether ideal affect match increases trust by reducing neural activity (in the right temporoparietal junction) associated with perception of different beliefs in others, as in previous research on sharing (Park et al., 2017). These findings may imply that trust and transfers can be enhanced in intercultural exchanges by adopting the valued emotional expression of the other culture.

3-M-43 How does social information influence charitable giving?: Behavioral experiments with eye-tracking

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Objective: Humans use personal money to benefit less well-off others. Given limited budget, however, we have to be selective about whom to help. This issue becomes pertinent in charitable giving for foreign countries when allocating money between unfamiliar targets. In those situations, we rely on social information about how others have donated to which targets. Previous research has investigated how accumulated amount to a target affect the decision about how much money to donate to the target, but has not addressed the "whom" question - who should be helped when there are several possible targets. One possibility is that people copy others' popular choice as evidence for the target's donation-worthiness (e.g., imminence of needs). However, it is also conceivable that people may be motivated to decrease "inequity" among the recipients - if one target is well-supported while the others are "neglected", people may be inclined to choose a less popular target. Here, we address this question using behavioral and eye-tracking data. Methods: Study 1: Participants were solicited to donate money to a charity from their own pockets. Only those who accepted the solicitation decided individually which of two charities (for Africa or Syria) to donate, and how much money to donate. They were then provided social information showing the amount of money already donated to each charity. In the "majority" ("minority") condition, a participant was presented with social information in which the charity chosen by the participant has received more (less) money than the other. Participants were then

asked to confirm their decisions (they could change their initial decisions if they wished). Study 2: Procedures were identical to Study 1 except that we collected the eye-tracking data, with eye movements as an index of allocation of attentions and pupil sizes as an index of emotional arousal. Results: Study 1: Contrary to the "conformity" hypothesis, none of the participants changed their decisions in the minority condition (no change from the unpopular to the popular option), whereas 21% of participants changed their decisions in the majority condition (change from the popular to the unpopular option). This pattern suggests that the "inequity aversion" was a major motivation when interpreting the social information. Study 2: The unpopular option attracted participants' attentions more than the popular option. Moreover, we found greater pupil dilations for the participants who changed their decisions compared with those who did not, suggesting that emotional arousal plays a role in switching behaviors after the social information. Conclusion: Our findings suggest that inequity aversion plays a role when people decide whom to help in charitable giving.

3-M-44 Peer presence increases pro-social behavior due to shifts in the speed with which others' rewards are processed

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Objective. Adolescence is characterized by heightened sensitivity to both reward and social context (e.g., Richards et al., 2013, Somerville, 2013). Although peer presence makes adolescents more sensitive to their own potential rewards (e.g. Chein et al., 2011), it is unknown whether this social context makes adolescents more sensitive to others' potential rewards as well. Here, we combine cognitive modeling and process tracing methods to show how peer presence changes the brain's processing of rewards to facilitate increased pro-sociality. Methods. Pairs of adolescents evaluated tradeoffs between reward for themselves and a friend first alone (N=57), and then while watched by a friend (N=55), and responded with a computer mouse. We used cognitive modeling to quantify how peer presence alters social preference for advantageous (self-reward greater) and disadvantageous (other-reward greater) inequality. Using methods developed in Sullivan et al. (2015), we use mouse cursor movement to estimate the speed with which self and other rewards were processed. Results. The Charness & Rabin (2002) advantageous-disadvantageous inequality model fit our data best, and adolescents exhibited larger model parameters when watched ($t(54)>-3.52$, $p<.001$). Simulations using a modified drift diffusion model demonstrate that pro-social behavior can be shifted simply by changing the time at which self and other payout information enters the decision process ("processing speed"; Sullivan et al., 2015). Next, we estimated these processing speeds using mouse position data. Across participants, processing speeds were faster for self than other reward ($z(54)=-3.47$, $p=.0005$). Confirming simulation results, faster other relative to self reward processing is correlated with multiple pro-sociality measures: greater decision weight for other, relative to self, reward ($R2=.22$, $p=3x10-6$), advantageous inequality parameter ρ ($R2=.15$, $p=.0001$), disadvantageous inequality parameter σ ($R2=.14$, $p=.0004$), and self-reported friendship quality ($R2=.05$, $p=.03$). Moreover, peer presence speeded the processing of other reward information ($z(54)=-3.35$, $p=.0007$). Conclusions. We combine cognitive modeling and process tracing to investigate how social context influences pro-sociality. We find that self rewards are processed earlier than other rewards, and that this explains a significant proportion of variance in pro-sociality. Peer presence changed preferences for advantageous vs. disadvantageous inequality, and speeds processing of rewards for others, which partially explains the observed increase in pro-sociality. These results suggest that peer presence has a positive influence through enabling faster incorporation of other-related information into the decision process.

N – Valuation & Value Systems

3-N-45 Prefrontal Cortex Mechanisms Of Preference Change In Cue-Approach Training - A Focal Lesion Study

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It has been recently shown that an individual item's subjective value can be perturbed in absence of reward through association of a cue and a button press ("cue-approach training"; Schonberg et al. , 2014). After training, subjects were more likely to choose items that had been paired with a cued button press, compared to uncued items previously rated as having similar subjective value. This effect persists over time, and has been replicated in several samples, using different types of stimuli. Evidence from fMRI showed that the enhanced preference for cued items was reflected in increased BOLD signal in the ventromedial prefrontal cortex (vmPFC) during choice, and other lines of evidence implicate this region, or adjacent orbitofrontal cortex (OFC), in flexible value updating. Here, we report preliminary data from a study asking whether the OFC is required for the cue-approach effect on subjective value. Twenty-four healthy participants (12 males, mean age 58.6, range 44-77) and 4 participants with prefrontal damage affecting the OFC (2 males, mean age 55.7, range 44-68) completed the cue-approach task with fractal images. Based on individual preferences, stimuli were classified as high value (HV) and low value (LV) items. In the choice phase, participants chose their preferred item from pairs of similarly valued stimuli, in which only one had been associated with a cue and a button press in the previous training phase (Go item). Replicating prior findings for the first time in elderly people, we found that healthy participants significantly preferred fractals that were associated with the cue (HV-Go stimuli were chosen in 59% of trials ($p=0.007$), LV-Go in 59%; $p=0.03$). Preliminary analysis showed variability across the 4 participants with OFC lesions, but overall, the OFC patients showed a weaker change in preferences following cue-approach training. This suggests that OFC may be necessary for changing value based on response experience even in the absence of explicit reward.

3-N-46 The vmPFC signal : a common neural currency for reward, effort and confidence

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Standard decision theory assumes that choices are based on a comparison of subjective values assigned to potential outcomes of available options. A great wealth of neuroimaging studies have implicated the ventromedial prefrontal cortex (vmPFC) in signaling such subjective values. Moreover, the vmPFC has been shown to reflect the subjective value of stimuli from various categories (money, food, painting, music etc.), giving rise to the notion of a common neural currency. The positive correlation between vmPFC activity and subjective value has been observed both for appetitive and aversive items, such as monetary gains and losses. Recently, it has also been demonstrated that the vmPFC encodes confidence (probability of being correct), which can be seen as a valuation of the response. However, it remains unclear whether the vmPFC would also integrate action cost, in particular the amount of effort associated to potential actions. Here, we addressed this question using fMRI while participants rate the likeability of both reward and effort items. We found that vmPFC activity correlates positively with reward rating (how pleasant it would be to be given the reward) and negatively with effort rating (how unpleasant it would be to be imposed the effort). Furthermore, vmPFC activity also reflected a quadratic function of both reward and effort rating, which in a previous study was shown to account for confidence level. These patterns were observed irrespective of the presentation mode (e.g., rewards presented as texts or images) and the particular sub-categories of presented items (e.g., food vs. non-food rewards, or cognitive vs. motor effort). Thus, our findings challenge the hypothesis that the vmPFC

would only valuate dimensions in the goods space (as opposed to the action space) and extends the notion of common neural currency.

3-N-47 How the brain uses reward distributions to compute inequality and value

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Rewards are almost never obtained in isolation. Rather, humans attain rewards in a social context, where comparisons can be made with many others. Here we ask how the brain uses such rich information to determine subjective value. In particular, which properties of the reward distributions are used and how are they combined to reach a measure of value? In a controlled laboratory experiment we vary the statistical properties of the income distribution of a group of individuals, loosely mimicking that of different countries on each trial. We then examine how the brain uses the statistical information embedded in such contexts to compute the subjective value of rewards and a measure of (in)equality. Using behavioural ratings and BOLD response in reward processing regions, we show that subjective value is best accounted for by a model that expresses value as a weighted sum of a person's rank and relative position in the income range. This model, which is based on Parducci's range-frequency theory, outperformed models based on inequality aversion, value-normalization and prospect theory. Further, we found that judgements of inequality were highly biased by the position of the individual in the distribution. In particular, the higher the position of the individual the more likely they were to perceive an unequal distribution as equal. Our findings provide a model of how people judge their (miss)fortune and that of others in a social context.

3-N-48 Ventromedial and ventrolateral prefrontal cortex reflect the value of choice-irrelevant attributes recalled from memory

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Objective: Animals often act as if maximizing an objective reward function. Common theories assume that animals use a running average over previous choices and stimulus attributes to predict the value of an action. However, the use of such memory-based summary statistics comes at considerable cost: Even when required, the animal cannot flexibly reweight the attributes to make optimal choices. Thus, memory of stimulus attributes ranges on a continuum from perfect knowledge of all values (multivariate code) to a summary statistic (univariate code). However, little is known about which part of this continuum different brain regions occupy. The ventromedial prefrontal cortex (vmPFC) has been implicated as a value comparison region and could thus support the univariate case, whereas the orbitofrontal cortex (OFC) is involved in the learning of attributes that were not currently relevant, thus potentially supporting the multivariate case. Methods: Here, we present a task using human fMRI in which participants first learned the bids of two potential buyers (the value attributes) for a number of cars. After this learning phase, no feedback was given. Subsequently, participants progressed through a series of markets in which they chose one of two cars to sell. Importantly, the optimal weighting of bids changed such that in some "single" markets only one buyer was available, whereas in some "mixed" markets the buyer was unknown, thus requiring participants to average potential bids. Participants were rewarded according to the value of the cars chosen on a few randomly selected trials. Results: Participants performed well in all three markets, choosing the higher valued car most of the time, indicating a multivariate value code. Logistic regression analyses revealed that their choices in the single markets were biased by the currently irrelevant attribute. This deviation from optimality was best explained by a partial normalization model, whereby remembered car values scaled with the relative difference between the two attributes. This lead to a loss in choice precision that was greatest for cars at

the high and low end of the value spectrum. In addition, vmPFC and ventrolateral PFC both scaled negatively with the irrelevant bid in a choice-independent fashion. The vmPFC also encoded the difference between the chosen and unchosen values in the relevant attribute. Discussion: We show that vmPFC is partially modulated by the value of currently irrelevant choice attributes, indicating a partial multivariate value code. Further multivariate analyses, such as representational similarity analysis, will investigate the dimensionality of value encoding in the PFC.

3-N-49 Impact of severe obesity on resting-state connectivity in brain systems related to valuation and self-control pre- vs. post-bariatric surgery (BS)

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Severe obesity is progressing worldwide and one of the more successful weight loss interventions is BS, which leads to substantial weight loss and amelioration of the metabolic state. It is, however, unclear if obesity affects intrinsic neural activity at rest and how BS changes such intrinsic neural activity affected by obesity. Here, we tested the effects of severe obesity and BS on resting state activity of the brain's valuation system (BVS, Bartra et al. 2010). 16 severely obese (BMI: mean±SD: 45.6±5.2) and 40 control (BMI: mean±SD: 22.3±1.9) women were scanned with resting-state functional magnetic imaging at two time points for both groups (i.e., T0 and T6). The obese patients were assessed before (T0) and six months after undergoing BS (T6). The lean controls were tested twice, at T0 and after a period of 6 months (T6) to control for effects of time. We looked for brain regions that co-varied in resting state activity with a neural hub of the BVS - the ventromedial prefrontal cortex (vmPFC) - in (1) obese versus lean participants at both time points (i.e., main effect of group) and (2) pre- versus post-BS (i.e., interaction group by time point: obese (T6>T0) > lean (T6>T0)). We found (1) an increased connectivity at rest between the vmPFC and cognitive brain regions such as the anterior and dorsolateral prefrontal cortex and (2) a decreased connectivity at rest between the vmPFC and motivational nodes such as the ventral striatum (vStr) in the obese as compared to the lean participants (i.e., a main effect of group, p corr<0.05). In addition, we found that BS impacted significantly the latter connectivity at rest between the vmPFC and the vStr.: We found that the vmPFC resting state connectivity to the vStr was stronger post-BS in the obese participants compared to the effect of time in the lean participants (p corr<0.05). Our findings suggest that severely obese participants exhibit stronger intrinsic neural activity within pathways that are known to underpin valuation processes and its control during dietary decision-making. This might be related to the specific medical treatment context requiring patients to engage in self-controlled behavior such as dietary intake control before the surgery. Furthermore, the weakened intrinsic neural activity within reward and motivation related pathways appears to be in line with the reward deficiency syndrome characteristic for addictions in general, which is defined by blunted striatal activation, due to repetitive exposure to a drug-like stimulus Interestingly, BS seemed to reintegrate the resting connectivity within these pathways suggesting an effective treatment not only on weight status but also on the brain, counteracting addiction-like brain connectivity.

3-N-50 No pain, no gain: psychophysical evaluation of the monetary value of pain

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Introduction/Aim: In order to make optimal decisions between goods of different nature, instrumental decision-making systems must base their choices on an abstract quantity: value (equivalent to the concept of utility in economy). In the present study, we aimed at determining the monetary value of pain in order to gain insight on how it influences reward seeking. Methods: 30 healthy volunteers were

recruited. Painful stimuli consisted of electric shocks (Digitimer) delivered on the ankle. We first determined the psychometric function of their pain sensitivity. Thereafter, participants underwent a decision-making task during which they had to accept or decline offers that included pairs of varying levels of pain (threshold to tolerance) and monetary compensations (0 to 5 $). Results: Our data show that the monetary value of pain increased as a function of stimulus intensity (t = 2.07, p = 0.007), with steeper increments in pain value when approaching pain tolerance. Conclusion: Our findings indicate that similar increases in perceived pain intensity yield greater gains in value when approaching pain tolerance than near-threshold levels.

3-N-51 Reward Processing Abnormalities in Unipolar Depression: A Meta-analysis of Neuroimaging Studies

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Over the past decade, a growing number of neuroimaging studies have investigated aberrant brain activation in different brain regions during reward processing in patients with unipolar depression (UD). Although these studies have generally endorsed the idea that the ventral striatum exhibits blunted responses to reward in UD, it remains unclear whether other brain regions consistently show aberrant responses to reward in UD. To investigate this issue, we performed a coordinate-based meta-analysis of neuroimaging studies investigating reward-processing abnormalities in UD. Our meta-analysis considered studies published between 1/1/1997 and 3/14/2017, as identified by searching the MEDLINE, EMBASE, PsycINFO, PsycARTICLES, Scopus, and Web of Science databases. Studies were included if they (a) reported comparisons between UD patients and healthy individuals, (b) used fMRI in conjunction with parametric analysis or subtraction methodology to identify foci of task-related neural changes contrasting an experimental condition and an active control condition, and (c) reported results of whole-brain group analyses in standard stereotactic coordinates. Our preliminary analyses used GingerALE (v2.3.6) and focused on studies examining hyper (N = 21) and hypo (N = 28) responses to reward in UD. We found that individuals with UD (relative to healthy controls) exhibited reduced activation in the ventral striatum during the performance of reward processing tasks. In addition, we also found that individuals with UD (relative to healthy controls) exhibited increased reward-related activation in the orbitofrontal cortex (OFC). These findings suggest that, during reward processing, individuals with UD show hypoactivation in the ventral striatum and hyperactivation in the OFC, consistent with previous studies suggesting that anhedonia severity in UD is negatively correlated with striatal activity and positively correlated with prefrontal cortex (e.g., Forbes et al., 2009; Keedwell et al., 2005). Our meta-analytic results suggest that UD may be tied to aberrant connectivity between the OFC and ventral striatum.

3-N-52 Rational Imprecision: Information-Processing, Neural, and Choice-Rule Perspectives

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Human choice behavior is stochastic. People do not make the same choice every time, even when faced with the same alternatives and the same information. This stochasticity means that people make mistakes, in the sense that they do not always choose the highest-valued available alternative. In this paper, we develop three models which each provide a distinct perspective on stochastic choice behavior: a neural implementation, an information-processing formulation, and a choice-rule characterization. Our neural implementation addresses how stochastic behavior may be implemented in the brain. It draws on a computation, called normalization, which has previously been shown to describe how the brain represents value. Normalization works by re-scaling the value of each choice alternative by a context-

dependent factor and then adding noise to each of these re-scaled values. Our information-processing formulation addresses why stochastic behavior arises in the first place--that is, why we make mistakes at all. Our answer comes from the inherent trade-off between the value of the chosen alternative and the cost of reducing choice stochasticity. In other words, optimal behavior must balance the costliness of more mistakes against the cost of reducing mistakes. Our choice-rule characterization gives an axiomatic description of stochastic behavior through a generalization of the independence-from-irrelevant-alternatives rule that underlies the classic Luce model of stochastic choice. A generalization of the Luce model is necessary to accommodate experimentally observed behaviors, such as the violations of regularity seen in the attraction effect. The main result in this paper is a theorem which establishes that all three of our models are fully equivalent in terms of the behavior they imply. In other words, any behavior that fits one of our models necessarily fits all three. One direction of this equivalence establishes that any behavior that arises from our neural-normalization implementation can be justified as the optimal solution to our information-processing formulation. Overall, we show that our three models constitute a single theory about stochastic choice, in which each model provides a different perspective on the same behavior.

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